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BLOCK AND GRAFT COPOLYMERS AND METHODS RELATING THERETO

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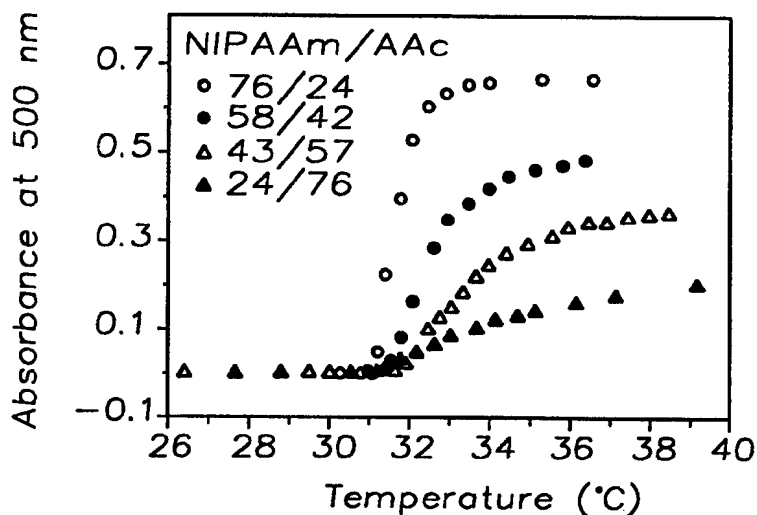
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(54) Title: BLOCK AND GRAFT COPOLYMERS AND METHODS RELATING THERETO

## (57) Abstract

There is disclosed block and graft copolymers which, in one embodiment, contain both a temperature-sensitive polymer component and a pH-sensitive polymer component, and the use of such copolymers for topical drug delivery to a treatment area. The block and graft copolymers may be physically mixed with one or more drugs to form a copolymer-drug mixture. This mixture may be applied to the treatment as solid particles suspended in a pharmaceutically acceptable carrier, or as a liquid which gels upon contact with the treatment area. Upon contact with the treatment area, the pH-sensitive polymer component hydrates and swells, thereby causing release of the drug from the mixture. In addition, such hydration and swelling causes the pH-sensitive polymer component to adhere to the tissue of the treatment area, thus prolonging contact time. The temperature-sensitive polymer component resists hydration and swelling of the mixture, thereby imparting a sustained and controlled release of the drug to the treatment area. In another embodiment of this invention, bloc and graft copolymers, and hydrogels thereof, are disclosed having broad industrial applicability.



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DescriptionBLOCK AND GRAFT COPOLYMERS  
AND METHODS RELATING THERETO

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Technical Field

This invention relates generally to block and graft copolymers, and more specifically, to block and graft copolymers which are effective in drug delivery, including copolymer-drug mixtures for the delivery and controlled release of a drug by topical application.

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Background of the Invention

The effective and efficient delivery of a therapeutic drug to a patient is a goal of pharmaceutical science. Targeted drug delivery, such as topical application of a therapeutic drug to a site of action, has many advantages over systemic drug delivery. Typically, adverse side effects associated with systemic delivery may be greatly reduced when a therapeutic drug is delivered locally to the site of action by topical administration. Therapeutic drugs which are systemically administered are dispersed relatively non-selectively throughout the patient's body and metabolized, thus reducing their therapeutic effectiveness with respect to dosage, as well as increasing the likelihood of adverse reaction. In contrast, an effective dosage of a topically administered therapeutic drug is often significantly less than that required through systemic administration. The diminution of dosage accompanying topical administration reduces the possibility of adverse reaction to the drug. In addition, drug metabolism of topically administered therapeutics is also minimized, thereby increasing their effectiveness.

While advantageous to systemic delivery, topical administration of a therapeutic drug is far from ideal. Perhaps the greatest single drawback to topical drug administration is the actual delivery of the therapeutic drug to the tissue to be treated. The absorption of the therapeutic drug by the tissue is often a slow process, and therefore requires a relatively long contact time between the tissue and the topical formulation containing the therapeutic drug. For example, topical administration of solutions of therapeutic drugs can be rather problematic. The use of viscous solutions, gels, ointments, lotions, patches, and inserts containing therapeutic drugs is a routine alternative to the administration of therapeutics in solution. These alternative formulations serve to enhance the contact time between the therapeutic drug and the tissue to be treated, thereby increasing the effectiveness of the topical treatment.

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Ophthalmic drug delivery presents unique problems. Traditionally, eyedrops are the preferred mode of topical delivery of therapeutic drugs to the eye. Indeed, solutions of therapeutic drugs are routinely administered by this technique. However, it is well known that a major loss of drugs administered to the eye is via the lacrimal drainage system. This drainage is so effective that only a small fraction of the therapeutic drug remains in contact with the eye for any extended period of time. Consequently, topical delivery of therapeutic drugs to the eye via an eyedrop solution is relatively ineffective and requires repetitive treatments. The usual alternatives to the administration of solutions, such as the use of ointments and lotions to prolong tissue contact, are not particularly suitable for drug administration to the eye. Ointments and lotions are physically difficult to administer to the eye, and drug dosage is therefore difficult to control. The use of solid inserts has also been utilized to deliver therapeutic drugs to the eye. While this technique does assure a slow, effective release of the drug, patients often experience difficulty in placing and removing the insert into the cul-de-sac of the eye.

An alternative approach to ophthalmic drug delivery is the use of therapeutic drug formulations which are liquids at room temperature and which are transformed into gels upon warming through contact with tissue. These formulations, deliverable to the eye as liquid drops, may be readily dispensed and their dosage controlled. More significantly, once the liquid formulation is transformed into a gel on the surface of the eye, drainage of the therapeutic drug is retarded and its residence time on the eye is prolonged. The gelling of these formulations is attributable to polymer components which undergo solution-to-gel transitions in response to relatively small changes in environmental conditions (also called "triggers"), such as temperature or pH. Polymers which undergo solution-to-gel transition upon changes in temperature are often referred to as "thermally gelling polymers" or "temperature-sensitive polymers." Similarly, polymers which undergo solution-to-gel transition as a result of a change in pH are generally referred to as "pH-sensitive polymers."

Temperature-sensitive polymers which form gels upon warming undergo a solution-to-gel transition at their lower critical solution temperature ("LCST"), also referred to as the "cloud point." The formation of the gel is believed to result from the gathering of portions of the temperature-sensitive polymers into hydrophobic microdomains which are maintained in aqueous solution by the hydrophilic portion of the polymer. Such temperature-sensitive polymers, although water soluble at low temperature, generally possess some hydrophobic character. The polymer's hydrophobic character is imparted by the monomer from which the polymer is derived. For example, poly(N-isopropylacrylamide) ("NIPAAm") is well known to change its structure in

response to temperature in aqueous solutions (see, e.g., Heskins et al., J. Macromol. Sci. Chem. A2, 1441-45, 1968). At temperatures below the LCST of NIPAAm (i.e., 32°C), polymer chains of NIPAAm hydrate to form an expanded structure, while at temperatures above the LCST the chains form a compact structure which excludes  
5 water. Thus, gel formation is due to the association of the relatively hydrophobic isopropyl groups of the NIPAAm polymer.

Temperature-sensitive polymers have been employed as vehicles for ophthalmic drug delivery. For example, block copolymers of ethylene oxide and propylene oxide have been disclosed in U.S. Patent No. 4,188,373 for this purpose.  
10 However, in this system, the concentration of the polymer must be adjusted to provide the desired solution-to-gel transition temperature. The drawback to this system is that in order to achieve a solution-to-gel temperature suitable for gelling at body temperature, the polymer must be present at a relatively low concentration. Thus, the ability to obtain a gel with the desired properties is limited by the desired physiologically  
15 useful temperature range. The necessity for a low polymer concentration, in turn, limits the amount of drug that may be administered by such a polymer system.

Polymers which are sensitive to changes in pH, such as polyacrylic acid ("polyAAc"), have also been utilized to form gels in situ, including use as vehicles in ophthalmic compositions. For example, U.S. Patent No. 4,888,168 discloses a  
20 composition containing the homopolymer polyAAc, and gel formation occurs upon the subsequent addition of an acidic component. Gel formation results in this case by an increase in viscosity associated with the protonation of the carboxylic acid groups at low pH. In water at neutral pH, the carboxy groups of polyAAc are ionized and the polymer is a liquid-in-water solution. Lowering the pH to 4.3-4.5 by the addition of an acid,  
25 such as citric acid, results in gel formation by decreasing the hydrophilicity and increasing the hydrophobicity of the polymer. An undesirable limitation of this system for use as an ophthalmic drug delivery vehicle is that gel formation requires sequential addition of two solutions (i.e., a first polyAAc solution and a second acid solution).

Due to the drawbacks of existing temperature-sensitive and pH-sensitive  
30 polymers to provide suitable vehicles for topical drug delivery, researchers have studied random copolymers containing these components for use as a vehicle for topical drug delivery. Such random copolymers, however, have not proved suitable for physiological application. In particular, random copolymers of temperature-sensitive and pH-sensitive monomers quickly lose their temperature sensitivity upon increasing the content or ratio  
35 of the pH-sensitive monomers. Thus, by employing a ratio of the pH-sensitive component sufficient to impart pH sensitivity to the random copolymer, such a ratio destroys the temperature sensitivity sought by incorporation of the temperature-sensitive

components. In addition, cross-linking such random copolymers to form a hydrogel does not alleviate the problem. For example, cross-linked hydrogels of a random copolymer of acrylic acid ("AAc") and NIPAAm, when used as a vehicle for drug delivery, releases the drug at a more rapid rate as the AAc content of the random  
5 copolymer is increased (Dong and Hoffman, J. Controlled Release 15:141-152, 1991).

Similarly, attempts have been made to employ aqueous solutions containing a mixture of temperature-sensitive and pH-sensitive polymers for ophthalmic drug delivery. Such mixtures, however, have also been met with only limited success. For example, U.S. Patent No. 5,252,318 is directed to aqueous mixtures of temperature-  
10 sensitive and pH-sensitive reversibly gelling polymers. At physiological temperature and in buffered saline, such physical mixtures, when used for drug delivery, tend to separate as the temperature-sensitive polymer precipitates and the pH-sensitive polymer dissolves. Thus, such polymer mixtures are largely ineffective due to loss of drug through drainage from the eye.

15 Despite the advantages associated with the use of gel-forming polymers as vehicles for topical ophthalmic drug delivery, limitations to their utility persist. As mentioned above, these formulations are delivered as solutions and are thus susceptible to drainage from the eye before gel formation can be effected. Accordingly, there is a need in the art for a simple, dosage reliable, topically administrable composition which  
20 provides for delivery of an therapeutically effective amount of a drug in a controlled release manner which does not suffer rapid drainage from the treatment area. In addition, there is a need in the art for methods relating to the use of such compositions for topical drug delivery. The present invention fulfills these needs, and provides further related advantages.

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#### Summary of the Invention

In brief, environmentally-sensitive block and graft copolymers are disclosed. Such copolymers are particularly useful as vehicles for the controlled release of therapeutic drugs. In this embodiment, this invention is directed to graft copolymers  
30 comprising a backbone pH-sensitive polymer component with a pendant temperature-sensitive polymer component grafted thereto, or a backbone temperature-sensitive polymer component with a pendant pH-sensitive polymer component grafted thereto. In either case, the graft copolymers have a lower solution critical temperature ("LCST") ranging from 20°C to 40°C at physiological pH.

35 In a related embodiment, there is disclosed block copolymers comprising a pH-sensitive polymer component and a temperature-sensitive polymer component joined thereto. As with the graft copolymers, the block copolymers of this invention

also have a LCST ranging from 20°C to 40°C at physiological pH.

The pH-sensitive polymer component of the block and graft copolymers preferably comprise a carboxylic acid-containing polymer component derived from polymerizable carboxylic acids (such as acrylic acid and methacrylic acid), and preferably are either homopolymers or copolymers containing only a limited quantity of comonomer. The temperature-sensitive polymer component has a LCST ranging from 20°C to 40°C at physiological pH, and may be a homopolymer or a random or block copolymer. The pH-sensitive or temperature-sensitive polymer components may also be lightly cross-linked, resulting in cross-linked block and graft copolymer hydrogels.

In another embodiment, the present invention is directed to a physical mixture of a block or graft copolymer with a pharmaceutically acceptable drug to form a copolymer-drug mixture. For topical application to a treatment area, the copolymer-drug mixture is applied as a solid particle suspended in a pharmaceutically acceptable carrier. Alternatively, the copolymer may be dissolved in a pharmaceutically acceptable carrier in combination with the pharmaceutically acceptable drug and applied as a liquid copolymer-drug mixture. Upon contact with the treatment area, the copolymer of the copolymer-drug mixture forms a gel. Thus, this invention also discloses compositions containing particles of the copolymer-drug mixture suspended in a pharmaceutically acceptable carrier, as well as compositions containing the copolymer and drug in combination with a pharmaceutically acceptable carrier. In yet a further embodiment, there are disclosed methods for topically delivering a drug to a treatment area by administering such a composition thereto.

In yet a further embodiment, a block or graft copolymer may be lightly cross-linked to form a hydrogel. Suitable hydrogels comprise a backbone pH-sensitive polymer component with a pendent temperature-sensitive component grafted thereto, or a backbone temperature-sensitive component with a pendent pH-sensitive component grafted thereto. In addition, block copolymer hydrogels are also disclosed comprising a pH-sensitive polymer component joined to a temperature-sensitive polymer component. Such hydrogels may contain one or more pharmaceutically acceptable drugs in, for example, a dissolved or dispersed form.

Still a further aspect of this invention involves block or graft copolymers (including hydrogels of the same) for general industrial use, including, for example, use as lubricants, moisturizers, bulk-formers and/or absorbents. In this context of the present invention, the block and graft copolymers may be used over a wide pH and temperature range.

Other aspects of the present invention will become evident upon reference to the attached figures and following detailed description.



### Brief Description of the Drawings

Figure 1 illustrates the temperature-sensitive behavior of 0.2 weight percent solutions of four block copolymers of poly(N-isopropylacrylamide) and polyacrylic acid ("NIPAAm-b-AAc"), with varying ratios of poly(N-isopropylacrylamide) ("NIPAAm") and polyacrylic acid ("AAc"), in aqueous phosphate buffered saline solution (pH 7.4).

Figure 2 illustrates the release of a drug (i.e., timolol) from NIPAAm-b-AAc copolymer-drug particles as compared to homopolyAAc-drug particles in phosphate buffered saline (pH 7.4) at 34°C.

Figure 3 illustrates the temperature-sensitive behavior of 0.2 weight percent solutions of four graft copolymers of NIPAAm-g-AAc with varying ratios of NIPAAm/AAc in aqueous phosphate buffered saline solution (pH 7.4), as well as a 50/50 physical mixture of the same.

Figure 4 illustrates the release of timolol from copolymer-drug particles of these graft copolymers of NIPAAm-g-AAc as compared to random copolymers of NIPAAm and AAc in phosphate buffered saline (pH 7.4) at 34°C.

Figure 5 illustrates the release of timolol from copolymer-drug particles of graft copolymers NIPAAm-g-AAc as compared to random copolymers of NIPAAm and AAc in phosphate buffered saline (pH 7.4) at 37°C.

Figure 6 illustrates the release of timolol from cast films of copolymer-drug mixtures of various graft copolymers of NIPAAm-g-AAc (oligomer molecular weight 2000 with 51 pendant chains/backbone; molecular weight 3300 with 31 pendant chains/backbone, molecular weight 5800 with 18 graft chains/backbone; polyAAc backbone molecular weight 250,000) in phosphate buffered saline (pH 7.4) at 34°C.

Figure 7 illustrates the rate of both timolol release and graft copolymer-timolol mixture dissolution from a cast film (oligomer molecular weight 3300 with 31 pendant chains/backbone; polyAAc backbone molecular weight 250,000) in phosphate buffered saline (pH 7.4) at 34°C.

Figure 8 illustrates the release of timolol from cast films of polymer-drug mixtures: random copolymer with 30% NIPAAm; graft copolymer with 30% NIPAAm where NIPAAm has molecular weight of 3,300; a physical mixture of NIPAAm (molecular weight 3,300) and homopolyAAc (molecular weight 250,000) (30:70); and homopolyAAc with molecular weight 250,000 in phosphate buffered saline (pH 7.4) at 34°C.

Figure 9 illustrates the temperature-sensitive behavior of 0.2 weight percent solutions of cooligoNIPAAm-BMA and oligoNIPAAm in distilled water.

Figure 10 illustrates the temperature-sensitive behavior of 0.2 weight percent solutions of cooligoNIPAAm-BMA and oligoNIPAAm in phosphate buffered saline (pH 7.4).

Figure 11 illustrates the temperature-sensitive behavior of 0.2 weight percent solutions of graft copolymer (NIPAAm-BMA)-g-AAc, cooligoNIPAAm-BMA and homopolyAAc in phosphate buffered saline (pH 7.4).

Figure 12 illustrates the release of timolol from copolymer-drug particles of graft copolymer (NIPAAm-BMA)-g-AAc in phosphate buffered saline (pH 7.4) at 34°C.

Figure 13 illustrates the release of timolol from cast films of copolymer-drug mixtures for various graft copolymers of (NIPAAm-BMA)-g-AAc for various compositions of NIPAA-BMA co-oligomer in phosphate buffered saline (pH 7.4) at 34°C.

Figure 14 illustrates the synthesis of a representative graft copolymer hydrogel of this invention.

Figure 15 illustrates the degree of grafting for representative graft copolymer hydrogels.

Figure 16 illustrates the swelling ratios for representative graft copolymer hydrogels (open circle: 0.5 weight percent cross-linker, 58.97% grafting; filled square: 2.0 weight percent cross-linker, 48.41% grafting; open square: 2.0 weight percent cross-linker, 65.27% grafting).

Figure 17 illustrates the rate of release of timolol from cast films of copolymer-drug mixtures for several graft copolymer hydrogels of (NIPAAm-BMA)-g-AAc in phosphate buffered saline (pH 7.4) at 34°C.

Figure 18 illustrates the temperature-sensitive behavior of 0.2 weight percent solution of a random copolymer of NIPAAm and AAc (89 mole % NIPAAm) at pH 4.0 and pH 7.4.

Figure 19 illustrates the temperature-sensitive behavior of a 0.5 weight percent solution of a commercially available block copolymer of ethylene oxide and propylene oxide ("EO/PO/EO").

Figure 20 illustrates the temperature-sensitive behavior of a 2.5 weight percent solution of a graft copolymer of the EO/PO/EO block copolymer of Figure 19 grafted to a homopolymer backbone of AAc (*i.e.*, EO/PO/EO-g-AAc).

Figure 21 illustrates the drug release (timolol maleate) from graft copolymers of EO/PO/EO-g-AAc at varying ratios of EO/PO/EP to AAc (*i.e.*, 10:90, 20:80 and 30:70). For comparison purposes, drug release from a homopolymer of AAc,

and a physical mixture of the AAc homopolymer and a EO/PO/EO block copolymer, are also illustrated.

Figure 22 illustrates drug release from graft copolymers of the EO/PO/EO block copolymer L-122 grafted to a homopolymer backbone of AAc at ratios of EO/PO/EO to AAc ranging from 10:90 to 50:50.

Figure 23 illustrates drug release from graft copolymers of various EO/PO/EO block copolymers (*i.e.*, L-61, L-92 and L-122) grafted to a homopolymer backbone of AAc at a ratio of EO/PO/EO to AAc of 30:70.

#### 10 Detailed Description of the Invention

The present invention is generally directed to environmentally-sensitive block and graft copolymers. Such copolymers are particularly effective in therapeutic drug delivery and, even more specifically, in the sustained and controlled release of a therapeutic drug. In this embodiment, the environmentally-sensitive block and graft copolymers of this invention may be physically mixed with one or more therapeutic drugs to form a copolymer-drug mixture. This mixture may then be administered as a solid particle (hereinafter referred to as a "copolymer-drug particle") to a treatment area by topical application. Alternatively, the environmentally-sensitive block and graft copolymers may be administered in the form of a liquid which, upon contact with the treatment area, forms a gel. As used herein, the term "treatment area" means any surface on or in an animal body suitable for topical application, including (but not limited to) the eye, an open wound or burn, and mucosal tissue (such as the respiratory and alimentary tracts and vagina), and which contains a sufficient water/ion content to hydrate the particle or gel upon contact.

More specifically, the copolymer-drug mixtures of the present invention may be administered to the treatment area in a composition wherein the copolymer-drug mixture is suspended as solid particles within a pharmaceutically acceptable carrier. The pharmaceutically acceptable carriers of this invention must not cause significant dissolution of, or drug release from, the copolymer-drug particles suspended therein. In one embodiment, the copolymer-drug particles may be suspended in a volatile carrier, such as a fluorocarbon propellant. Upon contact with the treatment area, such as the eye, the volatile propellant evaporates, leaving the particles on the surface of the eye. The particles then hydrate, swell and slowly release the drug from the copolymer-drug particle as it undergoes swelling and dissolution. In another embodiment, the copolymer-drug particles may be suspended in a non-volatile carrier, such as distilled or sterile water. As described above, upon contact with the treatment area, the particles hydrate, swell, and release drug during particle swelling and dissolution. Alternatively,

the copolymer may be dissolved in a pharmaceutically acceptable carrier in combination with the drug and administered in the form of a liquid copolymer-drug mixture, the copolymer component of which forms a gel upon contact with the treatment area. The physical changes which occur upon contact with the treatment area are discussed in greater detail below.

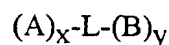
As used in the context of this invention, the term "drug" includes the definition set forth in 21 C.F.R. § 201(g)(1), "Federal Food, Drug and Cosmetic Act Requirements relating to Drugs for Human and Animal Use" (hereby incorporated by reference). Under this definition, a drug means (a) articles recognized in the official United States Pharmacopeia, official Homeopathic Pharmacopeia of the United States, or official National Formulary, or any supplement thereof; and (b) articles intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease in man or other animals; and (c) articles (other than food) intended to affect the structure or any function of the body of man or other animals; and (d) articles intended for use as a component of any articles specified in clause (a), (b) or (c) above; but does not include devices or their components, parts or accessories. Water is specifically intended to be included in the definition of the term drug as used herein. The term "cosmetic composition" includes compositions for skin care, hair care, care of nails, and toiletries, perfumes and fragrances. The term "superabsorbent" means a hydrogel which, starting from a dry material, will imbibe about 20 times its own weight of aqueous fluid (J. Gross, Absorbent Polymer Technology, L. Brannon-Peppas and R. Harland, ed., Elsevier, New York, New York, 1990, page 9)(incorporated herein by reference)

As mentioned above, in the practice of one embodiment of this invention, block and graft copolymers are used as a vehicle for the delivery of one or more drugs. The graft and block copolymers accomplish controlled and sustained drug release from the copolymer-drug mixtures through the physical properties of the component parts of the copolymer. Specifically, the block and graft copolymers of the present invention are comprised of two polymer components: a temperature-sensitive polymer component and a pH-sensitive polymer component. Upon contact with the treatment area, the pH-sensitive polymer component of the graft and block copolymers or hydrogels either hydrate and swell, or collapse, thereby causing release of the drug from the copolymer-drug mixtures. Hydration and swelling of the pH-sensitive polymer component is due to the uptake of both water and ions from the treatment area. For example, when the pH-sensitive polymer component is a carboxylic acid-containing polymer (such as polyAAc), the carboxylic acid groups ("COOH") are ionized by the uptake of cations (such as Na<sup>+</sup> or K<sup>+</sup>) from the treatment area to yield neutralized carboxylic acid moieties (i.e., COO<sup>-</sup>Na<sup>+</sup>). Ionization of the carboxylic acid groups is accompanied by the uptake of water

which, in turn, results in the swelling and gelling of the copolymer-drug mixtures. In addition, such hydration and swelling causes the pH-sensitive polymer component to adhere to the tissue of the treatment area (i.e., to become bioadhesive). In contrast to the pH-sensitive polymer component, the temperature-sensitive polymer component  
5 resists the hydration and swelling of the copolymer-drug mixture, thereby resulting in the sustained and controlled release of the drug from the copolymer-drug mixture.

As used herein, a "block copolymer" of the present invention has at least one temperature-sensitive polymer component terminally linked to at least one pH-sensitive polymer component (i.e., an end-to-end link). Similarly, a "graft copolymer" of  
10 the present invention has a pH-sensitive polymer component as a backbone polymer and at least one temperature-sensitive polymer component as a pendant polymer, or a temperature-sensitive polymer component as a backbone polymer and at least one pH-sensitive polymer component as a pendant polymer.

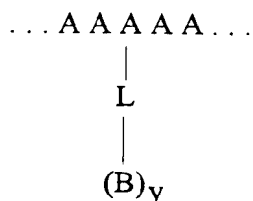
For purpose of clarity, a short review of polymer nomenclature would be  
15 helpful in understanding this invention. In general, a polymer is a macromolecule (i.e., a molecular chain) derived from the polymerization of monomer units. The links of the molecular chain are the monomer units. For example, polyacrylic acid (polyAAc) is a polymer derived from the monomer acrylic acid (AAc). More specifically, polyAAc is a "homopolymer," a polymer consisting of a single repeating unit, namely, AAc. In  
20 contrast, the polymers of the present invention are "copolymers." A copolymer is a polymer containing two (or more) different monomer units. A copolymer may generally be synthesized in several ways. For example, a copolymer may be prepared by the copolymerization of two different monomers. Such a process yields a copolymer where the two different monomers, commonly referred to as "comonomers," may be randomly  
25 distributed throughout the polymer chain. These copolymers are known as "random copolymers." Alternatively, copolymers may be prepared by the covalent coupling or joining of two homopolymers. For example, the covalent coupling of one homopolymer to the terminus of a second, different homopolymer provides a "block copolymer". A block copolymer containing homopolymer A and homopolymer B may be schematically  
30 represented by the following formula:



where  $(A)_x$  is a homopolymer of x monomers of A,  $(B)_y$  is a homopolymer consisting of  
35 y monomers of B, and L is a suitable covalent bond.

Depending upon the chemical nature of the homopolymer components, an additional type of copolymer may also be prepared. For example, as mentioned

above, polyAAc is a homopolymer of AAc moieties. Consequently, the polyAAc polymer chain is substituted with pendant carboxylic acid groups. The covalent coupling of a second, different homopolymer to one or more of these pendant carboxylic acid groups provides a "graft copolymer." Essentially, the second polymer is grafted onto the first. Thus, graft copolymers have a "backbone" polymer onto which one or more "pendant" polymers have been covalently attached. The nature of the graft copolymer may vary considerably depending upon the degree of substitution of the pendant polymers onto the backbone polymer. A graft copolymer having backbone homopolymer A onto which pendant homopolymer B is attached may be schematically represented by the following formula:



where "...AAAAA..." is a homopolymer of monomer A,  $(B)_y$  is a homopolymer of y monomers of B, and L is a suitable covalent bond.

The block and graft copolymers discussed above contain homopolymers A and B, which represent the temperature-sensitive polymer components and pH-sensitive polymer components of this invention. In addition, the block and graft copolymers of this invention may also be derived from polymers other than homopolymers. For example, rather than grafting pendant homopolymer B to backbone homopolymer A, copolymer CD may be grafted to homopolymer backbone A to yield a graft copolymer where the pendant polymer is itself a copolymer. In this case, homopolymer A corresponds to the pH-sensitive polymer component and copolymer CD is either a random copolymer or a block copolymer of comonomers C and D, and corresponds to the temperature-sensitive copolymer component. Alternatively, the backbone polymer may be the copolymer CD (which represents the temperature-sensitive polymer component), with the pendant polymer being the homopolymer A (which represents the pH-sensitive polymer component). The same is true for block copolymers--that is, copolymer CD (which represents the temperature-sensitive polymer component) may be used in combination with homopolymer A (which represents the pH-sensitive polymer component). While the pH-sensitive polymer component has generally been referred to as a homopolymer in the above discussion, the pH-sensitive

polymer component may itself be a copolymer subject to certain limitations which are discussed in greater detail below.

In the practice of this invention in the context of drug delivery, it is important that the graft and block copolymers undergo solution-to-gel phase transition at a temperature ranging from room temperature to just above physiological temperature. The solution-to-gel or precipitation phase transition (referred to herein as the "lower critical solution temperature" or "LCST") may be determined by absorbance spectroscopy by measuring the optical density of the block and graft copolymers in solution at a specific wavelength (such as 500 nm) as a function of temperature (Chen et al., Biomaterials 11:625-36, 1990). On warming to its LCST, the block and graft copolymers begin to aggregate, and the transmission of light decreases. The cloud point of a copolymer solution is defined as the temperature at which the solution has reached a certain value of its maximum opacity (such as 50%). (The determination of the LCST of several representative block and graft copolymer solutions of the present invention are provided in Figure 1, Example 1B, and in Figure 3, Example 2B, respectively.) Alternatively, the phase transition temperature may be determined by measuring the change in viscosity as a function of temperature. Upon warming to the LCST, the viscosity of a block or graft copolymer solution significantly increases as it undergoes the liquid-to-gel phase transition. This phase transition may be defined as the temperature at which the solution reaches a certain fraction of its maximum viscosity (such as 25%). Such viscosity measurements are preferred when the opacity of a copolymer solution does not significantly change when reaching the liquid-to-gel phase transition temperature. Other indicators of the phase transition include measuring the swell or collapse of the block or graft copolymer.

In one embodiment, the block and graft copolymers of the present invention have LCSTs (at a pH between 4.0 to 8.0) in the range from 20°C to 40°C, preferably in the range from 26°C to 34°C, and more preferably in the range from 28°C to 32°C. Preferably, the block and graft copolymers have the above LCSTs at a pH within the range from 6.0 to 8.0, more preferably from 7.0 to 7.8, and most preferably at a physiological pH of 7.4. In the context of this invention, the LCSTs of the block and graft copolymers are measured at an aqueous solution concentration generally below 10% by weight. It should also be understood that determination of the LCST within the above pH range does not exclude use of the block and graft copolymers at physiological conditions which may present higher or lower pHs. For example, very low pHs (pH 1) are encountered in the stomach, and the block and graft copolymers of this invention are suitable for oral administration thereto.

In the context of drug delivery, block and graft copolymers with LCSTs outside of the 20°C to 40°C range are generally not suitable for use in the practice of this invention. Copolymers with LCSTs below 20°C, in addition to being difficult to administer, are extremely resistant to dissolution and therefore are ineffective in drug  
5 delivery. Copolymers with LCSTs above 40°C will rapidly and completely dissolve at physiological temperature and pH, and therefore are ineffective in retarding drug delivery as a consequence of short residence period at the treatment area. (This aspect of the invention is discussed in greater detail below with regard to the bioadhesive properties of the block and graft copolymers of this invention.)

10 As mentioned above, the temperature-sensitive polymer component of the block and graft copolymers of this invention may be derived from homopolymers or copolymers. In either case, the temperature-sensitive polymer component has a LCST in the same range as that of the block and graft copolymers of this invention (i.e., for use as a drug delivery vehicle, in the range from 20°C to 40°C, preferably in the range from  
15 26°C to 34°C, and more preferably from 28°C to 32°C within the above-identified pH ranges). Thus, for drug delivery use, suitable temperature-sensitive polymers of this invention have LCSTs ranging from 20°C to 40°C, and confer an LCST of the same range upon their respective block and graft copolymers. In the context of this invention, the LCSTs of the temperature-sensitive polymers are measured at an aqueous solution  
20 concentration below 1% by weight, preferably from 0.01% to 0.5% by weight, and more preferably from 0.1% to 0.3% by weight.

Temperature-sensitive polymers of this invention may contain ester ether, amide, alcohol, and acid groups. These polymers may be synthesized by the polymerization of vinyl monomers such as acrylamide or N-isopropylacrylamide which  
25 provide polyacrylamide and poly(N-isopropylacrylamide), respectively, or esters of acrylic acid or methacrylic acid, for example, butyl acrylate or butyl methacrylate which provide poly(butyl acrylate) or poly(butyl methacrylate), respectively. Similarly, polymerization of cyclic ether monomers such as ethylene oxide provide polyethers and polymerization of vinyl acetate followed by hydrolysis provides polyalcohols. Suitable  
30 esters include esters of acrylic acid and its various derivatives such as methacrylic acid. Suitable ethers include ethylene oxide, propylene oxide, and vinyl methyl ether. Suitable alcohols include hydroxypropyl acrylate, and vinyl alcohol. Suitable amides include N-substituted acrylamides, N-vinylpyrrolidone, N-vinylacetamide, N-vinyl propionamide, N-vinylbutyramide, and ethyl oxazoline. Thus, block and graft  
35 copolymers of the present invention include temperature-sensitive polymer components containing polyesters, polyethers, polyalcohols, and polyamides. Preferably, the temperature-sensitive polymer components are selected from block copolymer of



polyethylene oxide, polypropylene oxide, random copolymers of ethylene oxide and propylene oxide, polyvinyl methyl ether, polyhydroxypropyl acrylate, polyvinyl alcohol, poly(N-substituted)acrylamides, poly(N-vinylpyrrolidone), and polyethyl oxazoline. Preferred temperature-sensitive polymers include poly(N-substituted acrylamides) and  
5 poly(N-substituted methacrylamides). These polyacrylamides may be derived from either unsubstituted or mono- or di-N-substituted acrylamides. The N-substituents of these acrylamides may be alkyl, C1-C10; cycloalkyl, C3-C6; or alkoxyalkyl, C2-C10. The disubstituted acrylamides may be cycloamides such as cyclopentyl and cyclohexyl amide derivatives or lactams such as caprolactam. In a preferred embodiment, the  
10 temperature-sensitive polymer component is poly(N-alkyl substituted) acrylamide. (The synthesis and properties of a representative temperature-sensitive homopolymer, poly-N-isopropylacrylamide (NIPAAm), is described in detail in Example 1A1.)

Alternatively, the temperature-sensitive polymers may be naturally occurring polymers (i.e., cellulose and its derivatives) which may be chemically modified  
15 to provide derivatives which possess the temperature-sensitive behavior required for the practice of the present invention. Suitable naturally occurring polymers include cellulose and its derivatives such as methylcellulose, hydroxypropyl cellulose, and hydroxypropyl methylcellulose.

In one embodiment, the temperature-sensitive polymer component is a  
20 homopolymer made by the polymerization of one of the above monomers. Alternatively, the temperature-sensitive polymer component is a random or block copolymer. Suitable temperature-sensitive copolymers include (but are not limited to) copolymers derived from the polymerization of hydroxypropyl acrylate and acrylamide or hydroxyethyl acrylate; hydroxyethyl acrylate and diacetone acrylamide or N-isopropyl  
25 acrylamide; N-isopropyl acrylamide and methacrylamide or methylacrylate; vinyl alcohol and vinyl acetate or vinyl butyrate; and vinyl acetate and vinyl pyrrolidone. For both homopolymer and copolymer temperature-sensitive polymer components, their LCST may be between 20°C and 40°C, and may confer an LCST to the resulting block and graft copolymers within the same range. (The synthesis of a representative temperature-  
30 sensitive copolymer, poly(N-isopropylacrylamide) butylmethacrylate (NIPAAm-BMA), is described in detail in Example 3A1.) In a preferred embodiment, the temperature-sensitive polymer component is a block copolymer of polyethylene oxide and polypropylene oxide. Such block copolymers are commercially available from BASF-Wyandotte Corp. (Wyandotte, Michigan) under the tradename Plurionics®, and have the  
35 general formula  $\text{HO}(\text{CH}_2\text{CH}_2\text{O})_a(\text{CH}_2\text{CH}(\text{CH}_3)\text{O})_b(\text{CH}_2\text{CH}_2\text{O})_a\text{H}$  where b is at least 15 and  $(\text{CH}_2\text{CH}_2\text{O})_{2a}$  is varied from 20-90% by weight. (The synthesis and properties

of representative copolymers having various Pluronics® grafted to polyAAc are described in detail in Example 6).

As mentioned above, the pH-sensitive polymer component of the graft and block copolymers of the present invention drives dissolution, as well as imparting bioadhesive properties and, in some instances, drug binding characteristics to the block and graft copolymer. As used herein, the term "bioadhesive" refers to the ability of the copolymer-drug mixture to adhere to the tissue of the treatment area upon hydration and swelling of the mixture. For example, when the treatment area is the eye, adhesion between the copolymer-drug mixture and the surface of the eye is due to the attractive interaction between chemical functional groups of the copolymer and eye's surface. The ionic nature of the pH-sensitive polymer component provides an adhesive interaction with the surface of the eye, thereby prolonging the residence time of the copolymer-drug mixture on the eye's surface.

In one embodiment, the pH-sensitive polymer component is a carboxylic acid-containing polymer, and may be derived from polymerizable carboxylic acids, including acrylic acid, methacrylic acid, ethacrylic acid,  $\beta$ -methylacrylic acid, cis- $\alpha$ -methylcrotonic acid, trans- $\alpha$ -methylcrotonic acid,  $\alpha$ -butylcrotonic acid,  $\alpha$ -phenylacrylic acid,  $\alpha$ -benzylacrylic acid,  $\alpha$ -cyclohexylacrylic acid,  $\beta$ -phenylacrylic acid, coumaric acid, and umbellic acid. Carboxymethylcellulose may also be a suitable carboxylic acid-containing polymer. In a preferred embodiment, the carboxylic acid-containing polymer is polyAAc.

In another embodiment, the pH-sensitive polymer component is an amine-containing, a phosphate-containing, a sulfate-containing, or a sulfonate-containing polymer component, or mixtures thereof. In a preferred embodiment, the pH-sensitive polymer component is an amine-containing or a phosphate-containing polymer component.

As described above, the pH-sensitive polymer component imparts bioadhesion to the block and graft copolymers of the present invention. In the case of carboxylic acid-containing polymer components, on contact with a treatment area, such as the eye or other mucosal tissue, the carboxylic acid moieties ionize and become carboxylate salts, for example, sodium carboxylate or potassium carboxylate. The transformation from carboxylic acid to carboxylate salt upon contact with the treatment areas results in hydration of the copolymer-drug mixtures. The bioadhesive properties of the mixtures are imparted upon hydration. Prior to hydration, the carboxylic acid form may also be bioadhesive. Ionization to the carboxylate salt causes the gel to swell and act "sticky", but it may lose its stickiness as it further hydrates. Similarly, the amine-, phosphate-, sulfate-, and sulfonate-containing polymer components are also capable of

ionizing upon contact with the treatment area. Specifically, ions present in the treatment area are taken up by these pH-sensitive polymer components to neutralize the ionizable moieties thereof. Ionization in turn is accompanied by water uptake, which causes the pH-sensitive polymer component, and thus the copolymer-drug mixture, to swell and become bioadhesive.

In a preferred embodiment, the pH-sensitive polymer component is a homopolymer (e.g., polyAAc). In a further embodiment, the pH-sensitive polymer component may be a copolymer derived from the copolymerization of two pH-sensitive monomers (e.g., acrylic acid and methacrylic acid), or a pH-sensitive monomer and a non-pH-sensitive monomer. In either case, the content of the comonomer (i.e., the non-pH-sensitive monomer or the different pH-sensitive monomer) must not be so great as to eliminate the bioadhesiveness of the pH-sensitive polymer component. In other words, the pH-sensitive polymer component should consist essentially of a single repeating monomer unit, with other monomer units present to an extent which does not significantly diminish the bioadhesive properties of the pH-sensitive polymer component. Typically, a single pH-sensitive polymer component will comprise in excess of 90% of the same pH-sensitive monomer, preferably in excess of 95%, and more preferably in excess of 99%.

In addition to imparting bioadhesiveness to the block and graft copolymer, hydration of the pH-sensitive polymer component also causes the block and graft copolymer to swell, which leads to the ultimate dissolution of the copolymer-drug mixtures. Swelling and dissolution in turn lead to drug release. For the block and graft copolymers of the present invention, their rate of swelling and dissolution or erosion rate is controlled by the resistance of temperature-sensitive polymer component to the swelling which is being driven by the ionization of the pH-sensitive polymer component.

The pH-sensitive polymer component of the block and graft copolymers of the present invention may also optionally bind the therapeutic drug via ionic interactions. For example, for therapeutic drugs which are cationic (i.e., positively charged), the anionic nature of the pH-sensitive polymer component (such as a carboxylic acid-containing polymer component) may ionically bind a cationic drug. (Such an interaction is described in Example 1C for timolol-hydrogen maleate, a cationic therapeutic drug, and anionic polymer component, polyAAc, of block copolymer NIPAAc-b-AAc.)

The copolymer-drug mixtures of this invention may be prepared by incorporation of the drug into the block or graft copolymer by physical entrapment, and/or by interaction with the pH-sensitive polymer component of the block or graft copolymer. This may be accomplished by dissolving the block or graft copolymer in a

solution containing the drug, and then precipitating the copolymer-drug solution into a non-solvent for the copolymer and drug, thus obtaining the copolymer-drug particles. (For example, the formation of particles of the drug timolol-hydrogen maleate and the copolymer NIPAAm-b-AAc is described in Example 1C.) Alternatively, the block or graft copolymer may be dissolved in a solution containing the drug, or dissolved in a solution to which the drug is then added, to yield a liquid copolymer-drug mixture. Such a solution may be further concentrated, or may be dried to yield, for example, a solid film. Suitable solutions include both aqueous and non-aqueous solvents. In one embodiment, the solution may contain at least 10% by weight of a non-aqueous solvent, and in a further embodiment may contain at least 99% by weight of a non-aqueous solvent.

As for the synthesis of the block and graft copolymers, such polymers may generally be synthesized by covalent coupling of a suitably reactive temperature-sensitive polymer component to a suitably reactive pH-sensitive polymer component. The covalent link between the two polymer components should be resistant to cleavage under conditions encountered following topical administration. Accordingly, suitable covalent linkages include amide, ester, ether, thioester, thioether, urea, urethane and amine linkages. Such linkages result from the coupling of a suitably reactive temperature-sensitive polymer component with a complementary pH-sensitive polymer component. For example, an amide linkage may be prepared either by coupling an amino-terminated temperature-sensitive polymer component with a carboxylic acid-modified pH-sensitive polymer component, or by the coupling of an amino-terminated pH-sensitive polymer component with a carboxylic acid-terminated temperature-sensitive polymer component. Other linkages may be similarly prepared by standard techniques. For example, representative syntheses of an amino-terminated pH-sensitive polymer (polyAAc) and a carboxylic acid-modified temperature-sensitive polymer (NIPAAm) are described in detail in Example 1A1 and 1A2, respectively. The coupling of these species to provide an amide-linked block copolymer is described in Example 1A3. A representative synthesis of an amino-terminated temperature-sensitive polymer component and its covalent coupling to a carboxylic acid-modified pH-sensitive polymer component to yield an amide-linked graft copolymer is described in Example 2A2.

Alternatively, graft copolymers of the present invention may be synthesized by the copolymerization of a suitable pH-sensitive monomer with a temperature-sensitive macromonomer. A representative synthesis of such a graft copolymer is described in detail in Example 2A1.

In one embodiment, the copolymers of the present invention are block copolymers. Block copolymers may be synthesized by the covalent coupling of the

terminus of a pH-sensitive polymer component to the terminus of a temperature-sensitive polymer component. The covalent linkage may be any one of the above-mentioned linkages, and in a preferred embodiment, the linkage is an amide linkage. The block copolymer may be prepared by the coupling of two homopolymers (e.g., a pH-sensitive homopolymer and a temperature-sensitive homopolymer), a homopolymer and a copolymer (e.g., a pH-sensitive homopolymer and a temperature-sensitive copolymer or a pH-sensitive copolymer and a temperature-sensitive homopolymer), or two copolymers (e.g., a pH-sensitive copolymer and a temperature-sensitive copolymer). A representative example of a block copolymer derived from the coupling of two homopolymers is described in Example 1.

In the context of drug delivery, suitable block copolymers of the present invention exhibit an LCST between 20°C and 40°C, and are derived from temperature-sensitive polymer components having an LCST between 20°C and 40°C. The block copolymers of the present invention preferably have an average molecular weight in the range from 5,000 to 100,000 (and may go as high as 500,000), and the temperature-sensitive polymer component preferably constitutes at least 10%-20% by weight of the block copolymer.

In another embodiment, the copolymers of the present invention are graft copolymers. Graft copolymers are synthesized by the covalent coupling of a suitably reactive polymer, either a pH-sensitive polymer component or a temperature-sensitive polymer component, to the pendant group of a backbone polymer, either a temperature-sensitive polymer component or a pH-sensitive polymer component. The covalent linkage may be any one of the above-mentioned linkages, and in a preferred embodiment the linkage is an amide linkage. The graft copolymer may be prepared by the coupling of two homopolymers (e.g., a pH-sensitive homopolymer and a temperature-sensitive homopolymer), a homopolymer and a copolymer (e.g., a pH-sensitive homopolymer and a temperature-sensitive copolymer or a pH-sensitive copolymer and a temperature-sensitive homopolymer), or two copolymers (e.g., a pH-sensitive copolymer and a temperature-sensitive copolymer). As discussed above, the temperature-sensitive polymer component of the graft copolymers of the present invention may be a block or random copolymer, provided that, in the context of drug delivery, the copolymer has an appropriate LCST. Similarly, the pH-sensitive polymer component is preferably a homopolymer, although block or random copolymers may be used to provide the bioadhesiveness of the pH-sensitive polymer-component is not significantly diminished. In a preferred embodiment, the graft copolymer has a pH-sensitive homopolymer backbone with pendant temperature-sensitive polymer components. A representative synthesis of a graft copolymer derived from the coupling of two homopolymers is

described in Example 2, and a representative synthesis of a graft copolymer derived from the coupling of a pendant temperature-sensitive copolymer to a pH-sensitive homopolymer backbone is presented in Example 3. In a preferred embodiment, the graft copolymer has a pH-sensitive homopolymer backbone of polyAAc with pendent  
5 temperature-sensitive Pluronics® (i.e., block copolymers of ethylene oxide and propylene oxide) grafted thereto, as disclosed in Example 6.

The graft copolymers of the present invention have either a pH-sensitive polymer backbone with one or more pendant temperature-sensitive polymer components, or a temperature-sensitive polymer backbone with one or more pendant  
10 pH-sensitive polymer components. The degree of substitution of the pendant polymer components on the backbone polymer may be controlled by the chemical coupling reaction. For example, by adjusting the ratio of pendant groups to be reacted with the backbone polymer, the properties of the graft copolymer product may be controlled and optimized. Graft copolymers with higher ratios of temperature-sensitive polymer  
15 components will possess relatively slower dissolution rates. Accordingly, a balance in the pH-sensitive and temperature-sensitive polymer components may provide an optimum copolymer which exhibits both preferred temperature-sensitive behavior with respect to dissolution and drug release, as well as preferred bioadhesion so as to provide extended residence time upon administration.

The graft copolymers of the present invention preferably have average molecular weights in the range from 100,000 to 600,000, and more preferably in the range from 250,000 to 500,000. In an alternative embodiment, the graft copolymers of this invention may have average molecular weights in the range from 50,000 to 1,000,000. In addition, the temperature-sensitive polymer component preferably  
25 constitutes at least 5%-10% by weight of the graft copolymer.

In a further embodiment of the present invention, the block and graft copolymers may be lightly cross-linked. These block and graft copolymers are referred to as "hydrogels." In one embodiment, the backbone polymer component is a cross-linked pH-sensitive polymer component with one or more pendant temperature-sensitive  
30 polymer components. In a preferred embodiment, the hydrogel is derived from a cross-linked pH-sensitive polymer backbone. Alternatively, the pH-sensitive polymer components of a block copolymer may be lightly cross-linked. Suitable cross-linking agents are well known and include (but not limited to) relatively "short" cross-linkers, such as methylene-bis-acrylamide and ethylene glycol dimethacrylate (EGDMA), as well  
35 as relative "long" cross-linkers, such as polyethylene glycol dimethacrylate (PEGDMA).

The cross-linked hydrogels of the block and graft copolymers effectively prevent rapid dissolution of the copolymer, while at the same time do not preclude

copolymer gelling. In some embodiments, it may be preferred that the crosslink density is sufficiently light that the hydrogels are soluble or erodible. In other embodiments, it may be preferred that the crosslink density is sufficiently great that the gel is a permanent "chemical gel" with a permanent three dimensional polymeric network, which maintains its structure and is not soluble or erodible. The level of crosslinking in a hydrogel is typically estimated by reporting the ratio of the molarity of crosslinker in solution to the molarity of monomer. However, since an actual crosslink is only formed when the crosslinker molecule links to two different polymer chains, the number of actual crosslinks may be only a small fraction of the number of crosslinker monomers present in the gel network. The hydrogels of the present invention are lightly cross-linked, and contain preferably from 0.001%-10% by weight. The level of actual crosslinking resulting from these crosslinker molecules is believed to be from 0.0001% to 2% actual crosslinks. Suitable concentrations of cross-linker in the polymerization reaction range from 0.05%-1% by weight based on total cross-linking monomer with a preferred range of 0.10%-0.50% by weight. The synthesis of a graft copolymer hydrogel is described in Example 4. As with the block and graft copolymers described above, the hydrogels of this invention are effective vehicles for the delivery of therapeutic drugs. Hydrogel copolymer-drug mixtures may be prepared by swelling the hydrogel in a solution containing the drug. Hydrogels include gels where the solvent is water, as well as gels where the solvent is significantly non-aqueous. In one embodiment, the solution may contain at least 10% by weight of a non-aqueous solvent, and in a further embodiment may contain at least 99% by weight of a non-aqueous solvent. Hydrogels of this invention include any graft or block copolymers containing pH-sensitive and temperature-sensitive components, independent of the LCST of the resulting hydrogel. In one embodiment of this invention, the hydrogels have an LCST ranging from 20°C to 40°C at physiological pH.

The copolymer-drug particles of the present invention may be formulated for topical administration as suspensions of solid particles in a pharmaceutically acceptable carrier, and one skilled in the art could readily prepare suitable formulations using known techniques and methods. Such formulations include, but are not limited to, solutions, creams and gels. The copolymer-drug particles may generally be present in these formulations in a range from 0.1% to 20% by weight of the total suspension, and preferably from 1% to 10% by weight of the total suspension. In the practice of this invention the copolymer-drug particles have a particle size on average, less than about 50  $\mu\text{m}$  in diameter, and preferably less than about 30  $\mu\text{m}$  in diameter. Particles larger than 50  $\mu\text{m}$  in diameter may be reduced to suitable particle size by mechanical milling or grinding.

As described above, the copolymer-drug particles may be suspended in a pharmaceutically acceptable carrier. In one embodiment, the pharmaceutically acceptable carrier may be a volatile carrier. Volatile carriers serve to transport the solid particles of the copolymer-drug particles to the treatment area and, upon contact with the treatment area, rapidly evaporate, to effectively deposit the particles on the treatment area. Suitable volatile carriers include fluorocarbon propellants (such as trichlorodifluoromethane and dichlorodifluoromethane) and such propellants may generally be present over a range from 5 to 20 times by weight the amount of copolymer-drug particles. The suspension of the copolymer-drug particles in the volatile carrier may be administered to the treatment area by any device suitable for effective delivery of the suspension. Effective delivery of the suspension preferably includes accurate and reproducible dosing of the copolymer-drug particles, and include metered dose nebulizers and devices which deliver the suspension as droplets (such as eye droppers).

In another embodiment, the copolymer-drug particles of the present invention may be administered as a suspension of particles in an aqueous carrier including distilled or sterile water. For ophthalmic administration, the osmolality of these aqueous compositions are preferably adjusted to physiological osmolality for physical comfort. Such aqueous compositions may have an osmolality of from about 50 to about 400 mOsM, preferably from about 100 to 300 mOsM, and more preferably about 150 mOsM. A suitable osmolality may be achieved by addition of a physiologically acceptable material such as a sugar or other nonionic compound.

In still a further embodiment, the copolymers of the present invention may be formulated for administration in liquid form by dissolving one or more of the copolymers in a pharmaceutically acceptable carrier. In one embodiment, the copolymer is present in these formulations at a sufficiently high concentration such that the formulation will gel upon contact with the treatment area. Typically, suitable concentrations of the copolymer in these formulations range from 0.1% to 20% by weight of the formulation, and preferably from 0.5% to 10% by weight of the formulation. In these formulations, the pharmaceutically acceptable drug may be present in a soluble or suspended form, or bound to a carrier. When the formulation gels upon contact with the treatment area, at least a portion of the drug present within the formulation is trapped within the gel.

In yet further embodiments, the copolymer-drug mixtures of this invention may be formulated as a solution, cream, gel, ointment, tablet, capsule or suppository. To this end, suppository formulations may be particularly suited for rectal administration of the copolymer-drug mixtures, while tablet and capsule forms are



suitable for administration to the alimentary tract, including the stomach. Solutions, creams, gels and ointments are, for example, preferred for topical skin applications. The copolymer-drug mixtures may also be formulated for nasal or buccal administration by known techniques. Formulations for general systemic delivery are also within the scope of this invention, and are readily prepared using known techniques.

Physical mixtures of the block and graft copolymers of this invention with one or more polymers, including homopolymers (such as a homopolymer of AAc) and copolymers (such as random or block copolymers of EO/PO/EO) are included within the scope of this invention.

As mentioned above, in the context of drug administration the block and graft copolymers of this invention preferably have LCSTs in the range from 20°C to 40°C. However, the graft and block copolymers (and hydrogels of the same) are not limited to only block and graft copolymers which satisfy this requirement. For example, cosmetic compositions, wound dressings, iontophoretic devices, monitoring electrodes, adhesives, suntan lotions, creams, foams, suppositories, tablets, and delivery gels may incorporate the block and graft copolymers of this invention having LCSTs well outside the above range. Furthermore, nasal, vaginal, oral ocular, rectal, dermal or otic delivery may similarly benefit by use thereof, as well as laxatives containing the same. With regard to vaginal delivery, the block or graft copolymer (or hydrogel) may be combined with a spermicide, ovacide, antimicrobial, antifungal, prostaglandin, steroidal or nonsteroidal fertility agent.

The block and graft copolymers (and hydrogels thereof) may also be used to control reactive chemistry, separation of solution components, separation of ionic species or control of chemomechanical work, as well as for controlling viscosity or flow. Such copolymers (and hydrogels) may further be used to form a water or gas impermeable barrier between a well casing and surrounding rock formation. In such industrial settings, the block and graft copolymers (and hydrogels) of this invention may be used over a wide temperature range (-20°C to 250°C). Similarly, in both industrial and drug-delivery applications, they may also be used over a wide pH range (pH 0 to 16).

The block and graft copolymers of this invention, particularly the hydrogels thereof, may also be used as an absorbent agent, and preferably as superabsorbent agents, by exposing the hydrogel to a solvent or solution. Suitable solvents or solutions in this context include (but are not limited to) urine, feces, water, blood, brine, and ionic water solutions. Thus, the hydrogels may be used as an absorbing component of a diaper, and preferably with a swelling ratio of not less than

15. The block and graft copolymers, and hydrogels thereof, may also be used to provide moisture to, retain moisture at, or provide hydration to, the treatment area.

While the above disclosure is generally directed to block and graft copolymers comprising pH-sensitive and temperature-sensitive components, it should be  
5 recognized that polymer components which are sensitive to other environmental triggers may be employed. Thus, as used in the context of this invention, an environmentally sensitive polymer is a polymer that reversibly undergoes a change from primarily hydrophilic to primarily hydrophobic in response to a change in an environmental  
10 condition, such as temperature, pH, solvent or solvent concentration, ions or ionic concentration, light, or pressure. Materials and gels which exhibit these changes are known in the art. Tanaka, Physical Review Letters 40(12):820-823, 1978; Tanaka et al., Physical Review Letters 38(14):771-774, 1978; Tanaka et al, Physical Review Letters 5  
45:1636, 1980; Ilavsky, Macromolecules 15:782, 1982; Hrouz et al, Europ. Polymer J., 17:361, 1981; Ohmine et al, J. Chem Phys. 8:6379, 1984; Tanaka et al, Science  
15 218:462, 1982; Ilavsky et al, Polymer Bull. 7:107, 1982; Gehrke, Responsive Gels: Volume Transitions II; ed K. Dusek, Springer-Verlag, New York, pp. 81-114, 1993; Li  
et al, Ann. Rev. Mat. Sci. 22:243-277, 1992; Galaev et al, Enzyme Microb. Technol. 15:354-366, 1993 and Taylor et al, J. Polymer Sci. 13:2551-2570, 1975 (all of which are  
20 incorporated herein by reference). This change in hydrophilic to hydrophobic character may be evidenced by a decrease in transmission of light (cloud point), change in viscosity or swelling or collapse. As mentioned above, if an environmentally sensitive polymer undergoes the change in response to a change in temperature, it is a temperature-sensitive polymer, and if it undergoes the change in response to a change in pH, it is a pH-sensitive polymer.

25 Accordingly, in another embodiment of this invention, block and graft copolymers are disclosed which contain environmentally-sensitive polymer components which are responsive to different triggers. For example, block and graft copolymers containing two different pH-sensitive polymer components, or two different temperature-sensitive polymer components, may be used. Alternatively, the block and  
30 graft copolymers of this invention may contain, for example, a light-sensitive polymer component in combination with either a temperature-sensitive or pH-sensitive polymer component, or in combination with a different light-sensitive polymer, or in combination with a polymer component sensitive to other triggers

The following examples are provided for purposes of illustration, not  
35 limitation.

## EXAMPLES

Example 1

5                    Environmentally-Sensitive Block Copolymers Comprising  
                    Temperature Sensitive and pH-Sensitive Homopolymer Components

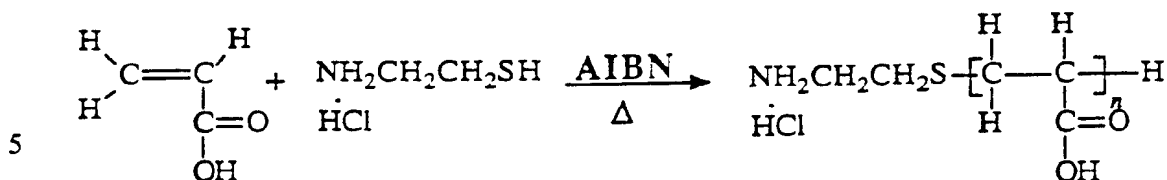
10                   In this example, the synthesis and characterization, temperature-sensitive behavior, and drug loading and release properties of block copolymers comprising a temperature-sensitive polymer component and a pH-sensitive polymer component is described.

A.        Synthesis and Characterization of Block Copolymers NIPAAm-b-AAc

15                   Block copolymers (NIPAAm-b-AAc) comprising a temperature-sensitive polymer component (NIPAAm) and a pH-sensitive polymer component (AAc) were synthesized from oligomers of NIPAAm and AAc. The block copolymers were prepared by covalently coupling an amino-terminated AAc oligomer to the active ester carbonyl-terminated NIPAAm oligomer to yield an amide linked block copolymer (see 3. below). In the present method, an amino group was introduced into one end of the AAc oligomer (see 1. below) and an active ester group (an N-hydroxy succinimide group) was introduced into one end of the NIPAAm oligomer (see 2. below).

1.        Synthesis of Amino-Terminated OligoAAc

25                   The amino-terminated oligoAAc was synthesized by radical polymerization of acrylic acid (AAc) using azobisisobutyronitrile (AIBN) as an initiator and 2-aminoethanethiol hydrochloride (AET-HCl) as a chain transfer reagent. The polymerization was carried out at 60°C using methanol as solvent. After polymerization, the polymer was collected by precipitating into diethyl ether, redissolving in dimethylformamide (DMF) mixed with triethylamine to remove the salt, and reprecipitating into diethyl ether. By changing the ratio of monomer to chain transfer reagent, the amino-terminated oligoAAc could be obtained with different molecular weights. The synthesis of the amino-terminated oligomers of AAc is represented schematically below.



The molecular weights of the oligomers were determined by end-group analysis as disclosed in Hazra et al., *Analytical Biochemistry* 137: 437-43 (1984). In this method, 2,4,6-trinitrobenzenesulfonic acid (TNBS) was reacted with the amino end group, and the absorbance of the product at 420 nm was measured. A calibration curve was established using three different amines with different numbers of carbons as follows:  $\text{H}_2\text{N}(\text{CH}_2)_2\text{COOH}$ ,  $\text{H}_2\text{N}(\text{CH}_2)_3\text{COOH}$ , and  $\text{H}_2\text{N}(\text{CH}_2)_5\text{COOH}$ . Table 1 summarizes the synthetic conditions and results for the polymerizations of AAc.

Table 1: Polymerization of AAc

AAc:AIBN:AET:HCl (mole)	Polymn. Time (h)	Yield (%w/w)	MW <sup>a</sup>
100:1:1	3.0	90	15200
100:1:2	3.5	73	6600
100:1:4	4.0	77	3500
100:1:6	4.0	55	2200
100:1:8	4.0	56	1500
100:1:10	4.0	42	1200

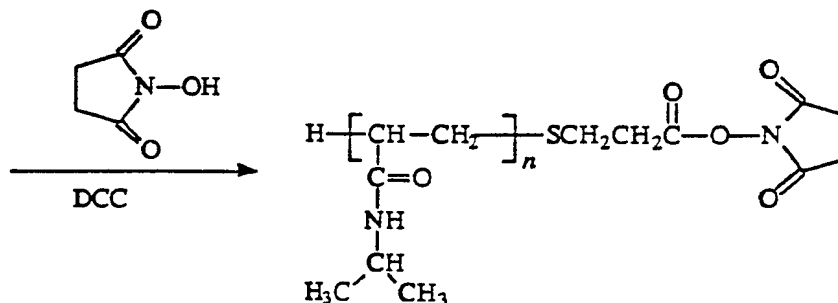
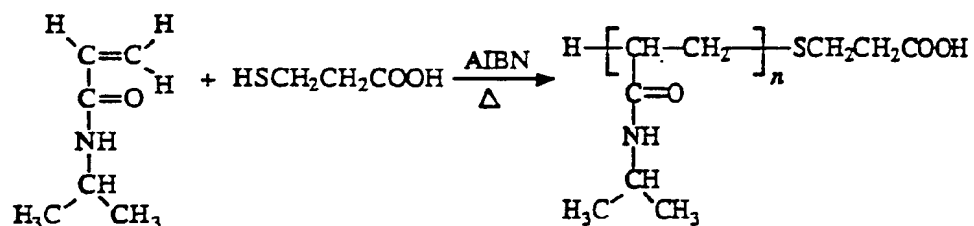
\*Concentration of monomer in methanol: 3.5 mole/L, polymerization temperature: 60°C;

<sup>a</sup>The molecular weight (MW) of the oligomer was determined by TNBS.

The molecular weight of the oligomers was controlled by changing the ratio of monomer to chain transfer reagent, molecular weights ranging from 1200 to 15,200 were obtained. From the data in the table shown above, the chain transfer constant for this system was calculated to be  $C_s = 0.62$ . These oligomers were used for the further synthesis of the block copolymer of NIPAAm-b-AAc.

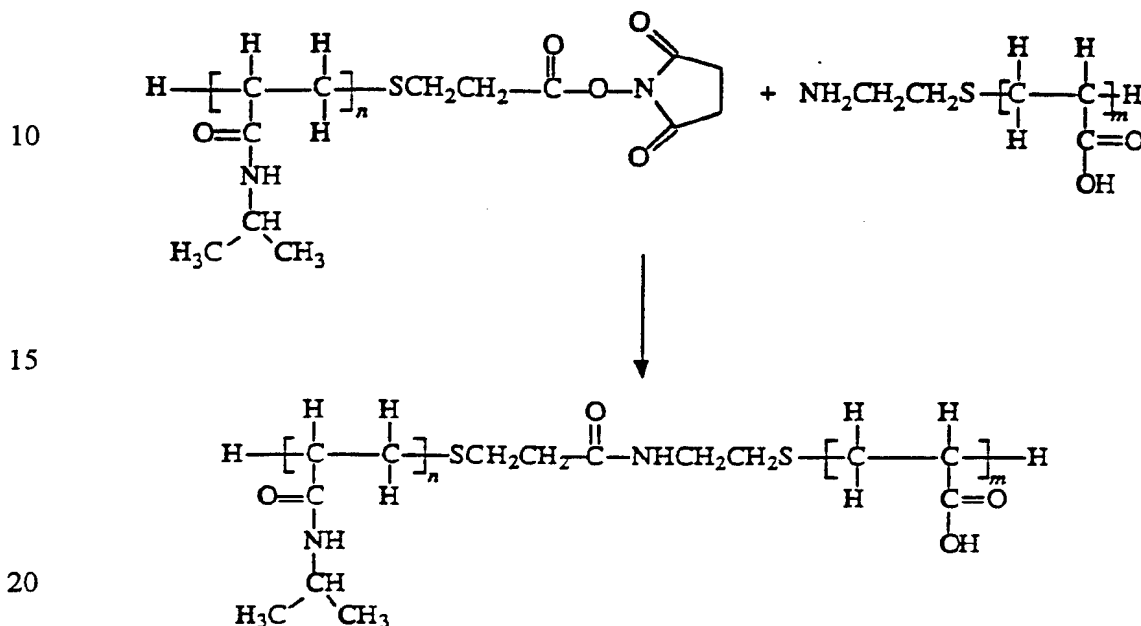
## 2. Synthesis of NHS-Activated OligoNIPAAm

The NHS-activated oligoNIPAAm was prepared in two steps. First, the carboxy-terminated oligoNIPAAm was prepared by radical polymerization using AIBN as an initiator and 2-mercaptopropionic acid as a chain transfer reagent. The polymerization was carried out at 60°C using tert-butanol as solvent and the polymer was collected by precipitating into diethyl ether. Secondly, the carboxyl group at the end of oligoNIPAAm was activated by N-hydroxy succinimide (NHS) in the presence of an activating reagent, dicyclohexylcarbodiimide (DCC), in methylene chloride at 0°C-20°C for 24 hours. After activation, the polymer was recovered by precipitating into diethyl ether (see, Chen and Hoffman, *Bioconjugate Chem.* 4: 509-14, 1993). The synthesis of the NHS-activated oligomers of NIPAAm is represented schematically below.



### 3. Synthesis of Block Copolymer NIPAAm-b-AAc

The block copolymer of NIPAAm-b-AAc was synthesized by coupling the amino-terminal group of the oligoAAc with the NHS-activated carboxyl group of the oligoNIPAAm by reaction in DMF at 60°C overnight. The synthesis of the block copolymers of NIPAAm-b-AAc is represented schematically below.



The reaction mixture was poured into ethyl acetate to precipitate the block copolymer product and unreacted oligoAAc. The unreacted oligoNIPAAm is soluble and remained in solution. The precipitate containing the product block copolymer and unreacted oligoAAc was then collected by filtration and dissolved in pH 7.4 phosphate buffer. The addition of saturated aqueous ammonium sulfate solution precipitated the block copolymer which was collected by filtration and washed with dilute hydrochloric acid to remove residual ammonium sulfate. The block copolymer was dried in a vacuum oven overnight. Table 2 presents the results of the block copolymer synthesis.

Table 2: Compositions of Block Copolymers NIPAAm-b-AAc

	1	2	3	4
Percent of NIPAAm	76%	58%	43%	24%
oligoNIPAAm MW	4800	4800	4800	4800
oligoAAc MW	1500	3500	6600	15200
Total MW	6300	8300	11400	20000

Block copolymers of NIPAAm-b-AAc with four different compositions were synthesized. The temperature-sensitivity properties of these block copolymers are described below.

#### B. Temperature-Sensitive Behavior of Block Copolymers of NIPAAm-b-AAc

The phase transition behavior of the block copolymer is a critical property for topical drug delivery. To investigate the phase transition behavior of the copolymers, a spectroscopic method was used to determine the light transmission (or absorbance) of the copolymer solution at 500 nm as a function of time during a constant rate of temperature rise. Below the phase transition temperature (also known as LCST or cloud point), light transmission is 100%. However, when the phase transition temperature is reached, the polymer begins to aggregate and light transmission of the solution decreases, absorbance increases.

As illustrated in Figure 1, all of the block copolymers prepared as described above exhibit a cloud point (LCST) near 32°C (2°C below eye temperature). However, only the highest NIPAAm content block copolymer, 76% by weight, showed a relatively sharp phase transition. The common cloud point for the different block copolymers indicates that the temperature-sensitivity of the oligoNIPAAm component changes very little after being end-linked to other hydrophilic polymers.

#### C. Drug Loading and Release from Block Copolymers of NIPAAm-b-AAc

##### 1. Drug Loading

Generally, in this method, the block copolymer NIPAAm-b-AAc and the drug timolol-hydrogen maleate salt (timolol) were dissolved in a solvent (methanol) to yield a solution of the block copolymer and drug. The block copolymer-drug particle was recovered by precipitation into a non-solvent (diethyl ether). For example, the block copolymer with 20 wt% of NIPAAm and a total molecular weight of 19,000

(4,000 for oligoNIPAAm and 15,000 for oligoAAc) was used to prepare exemplary block copolymer-drug particles. A solution of 0.6 g of the copolymer and 6.0 mg of the drug in 8 mL of methanol was prepared. This solution was precipitated into 800 ml of ether. The precipitated block copolymer-drug particles were recovered by filtration, washed three times with ether and dried under vacuum at room temperature. The recovery was 65% with a drug content of 1.1 wt%. In a control experiment, homopolymer (polyAAc)-drug particles were prepared in the same procedure as described above, except homopolyAAc having a molecular weight of 250,000 was used instead of the block copolymer NIPAAm-b-AAc. In this experiment, the percent recovery was 93% with a drug content of 1%. These materials were ground into small particles (ca. 20-40 $\mu$ ) for the drug release study described below.

## 2. Drug Release

Solutions of 10 mg of the block copolymer with 1.1 wt% drug prepared as described above and polyAAc with 1% drug in 15 mL of PBS buffer (pH 7.4) were prepared. The solutions were well-stirred during the drug release process. The amount of drug release from the polymers was determined by circulating the buffer to an absorbance spectrophotometer where the absorbance of the drug solution at 294 nm was measured as a function of time. The drug release results are presented in Figure 2.

Despite the higher molecular weight of homopolyAAc (molecular weight 15,000), the drug release from the block copolymer NIPAAm-b-AAc (molecular weight 4,000) was significantly slower. Referring to Figure 2 above, 80% drug release from the block copolymer requires 12 minutes, while the same extent of drug release occurs in 5 minutes with homopolyAAc. For comparative purposes, release data for graft copolymer NIPAAm-g-AAc and random copolymer NIPAAm-AAc is presented in Figure 5. Note that 80% drug release is achieved in 8 minutes for the graft copolymer NIPAAm-g-AAc (20% by weight NIPAAm) and in 3 minutes for the random copolymer NIPAAm-AAc (30% by weight NIPAAm).

The slower release rate from the block copolymer may be attributed to its temperature-sensitive component, NIPAAm. At 34°C, the NIPAAm component aggregates and becomes hydrophobic, resulting in a kind of gelation of the block copolymer-drug mixture, leading to a retardation in both dissolution rate and drug release rate. In fact, it was found that the block copolymer was not quite soluble but only swollen in PBS buffer (pH 7.4) at 34°C.

Figure 2 shows that a reduction in drug release rate is obtained compared to homopolyAAc by using the block copolymer as a matrix, even for a block copolymer with a total molecular weight of only 19,000 and only 20 wt% of NIPAAm component.



## Example 2

### Environmentally-Sensitive Graft Copolymers Comprising Temperature-Sensitive and 5 pH-Sensitive Homopolymer Components

In this example, the synthesis and characterization, temperature-sensitive behavior, and drug loading and drug release properties of graft copolymers comprising a temperature-sensitive homopolymer component and a pH-sensitive homopolymer  
10 component is described. Because of the nature of graft copolymers, two general embodiments are possible. The graft copolymer may possess a pH-sensitive polymer backbone with one or more pendant temperature-sensitive polymer components. Alternatively, the graft copolymer may have a temperature-sensitive polymer backbone with one or more pendant pH-sensitive polymer components. This example is directed  
15 to a graft copolymer with a pH-sensitive homopolymer backbone with pendant temperature-sensitive homopolymer components.

#### A. Synthesis and Characterization of Graft Copolymers NIPAAm-g-AAc

Graft copolymers (NIPAAm-g-AAc) comprising a temperature-sensitive  
20 homopolymer component (NIPAAm) and a pH-sensitive homopolymer component (AAc) were synthesized by two methods. The graft copolymers were synthesized by copolymerization of AAc with a macromonomer of NIPAAm and by the conjugation of oligomeric NIPAAm to polyAAc.

#### 25 1. Macromonomer Copolymerization Method

Copolymerization of acrylic acid and an appropriate macromonomer of NIPAAm results in the formation of a comb-like graft copolymer having a polyAAc backbone with pendant oligoNIPAAm side chains. The macromonomer of NIPAAm appropriate for copolymerization with acrylic acid is prepared from an amino-terminated  
30 oligoNIPAAm as described below.

a. Synthesis of Amino-Terminated OligoNIPAAm and its Corresponding Macromonomer

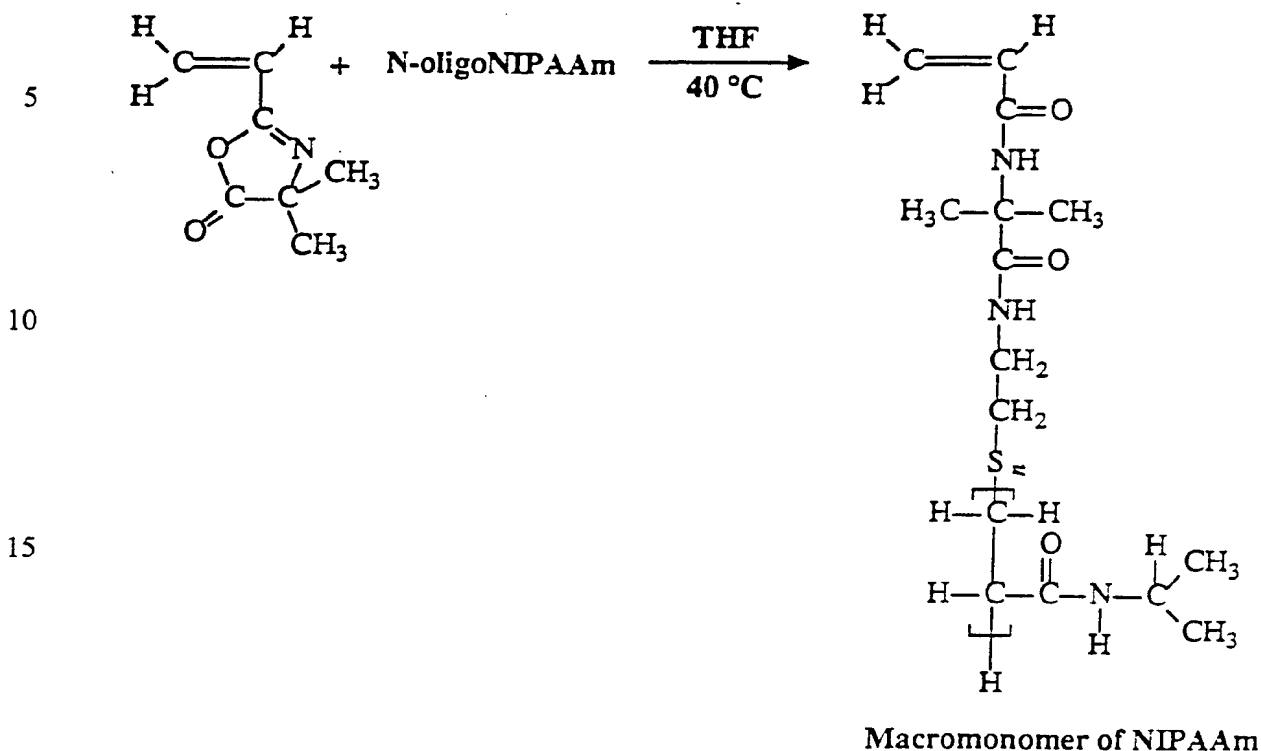
OligoNIPAAm was synthesized by free radical polymerization of NIPAAm in methanol solution (2.5 M NIPAAm) using AIBN and AET-HCl as initiator and chain transfer reagent, respectively. The polymerization was carried out at 60°C for 22 hours. The results for two representative syntheses are presented below in Table 3.

Table 3: Polymerization of NIPAAm

NIPAAm:AIBN:AET-HCl	Yield	MW <sup>a</sup>
100:1:12	59.7	3300
100:1:8 <sup>b</sup>	68.5	2200

<sup>a</sup>Molecular weight was estimated by conductometric titration with sodium hydroxide;  
<sup>b</sup>pH of the monomer solution was adjusted to 1.0 prior to polymerization.

The macromonomer of NIPAAm may be prepared by reaction of an amino-terminated oligoNIPAAm with vinyl azlactone. In a representative synthesis, a solution of 5.0 g (2.27 mmol) amino-terminated oligoNIPAAm (MW 2200) and 0.94 g (6.79 mmol) vinylazlactone in 120 mL tetrahydrofuran was stirred at 40°C for 16 hours. The reaction mixture was precipitated into 1000 mL diethyl ether and the resulting precipitate was collected by filtration. The product was isolated in 82% yield. The synthesis of the macromonomer of NIPAAm is presented schematically below.



b. Copolymerization Reaction

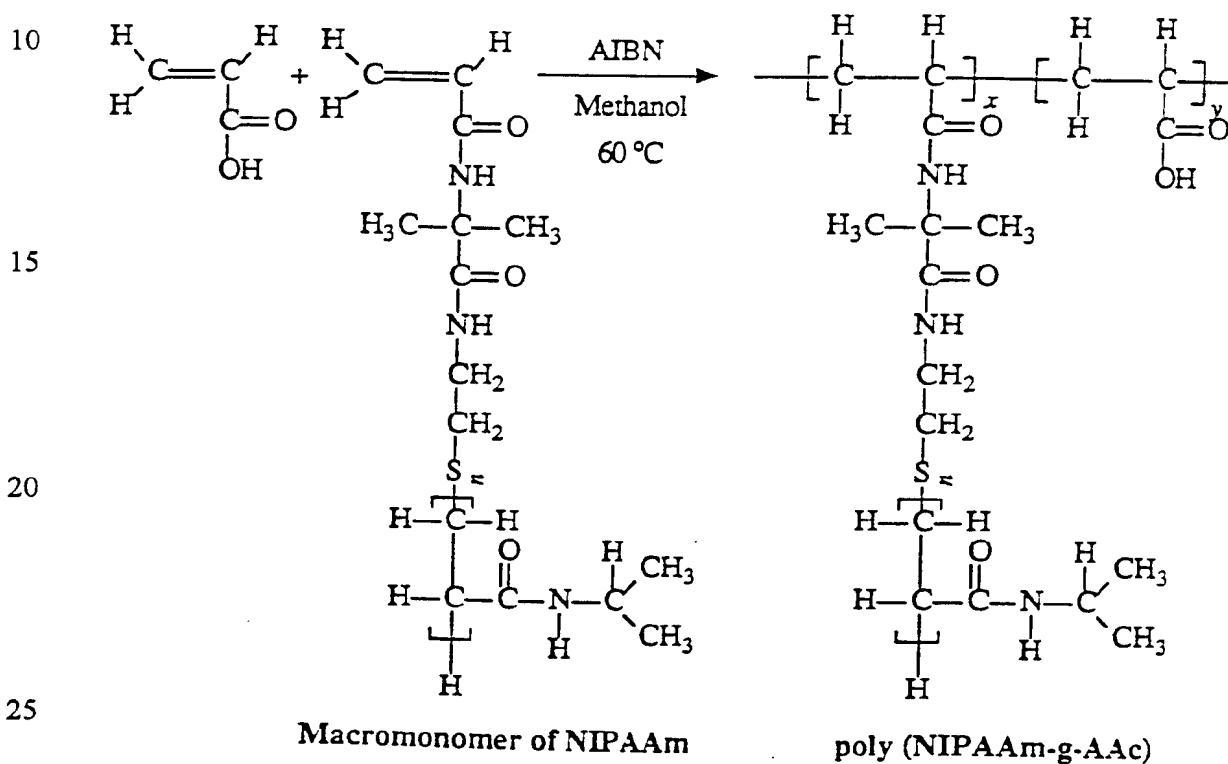
25 The graft copolymer NIPAAm-g-AAc was prepared by copolymerization of AAc with the macromonomer of NIPAAm prepared as described above. In a representative polymerization, the monomer concentration was 12% weight/volume in methanol with AIBN as initiator. The polymerization was carried out at 60°C for 1.5 hours. The copolymer product was collected by precipitation into methyl ethyl ketone, and was further purified by reprecipitation into tetrahydrofuran. The results for two

30 representative syntheses are presented below in Table 4.

Table 4: Copolymerization of AAc and Macromonomer NIPAAm

Feed		Yield	Copolymer	
$W_{AAc}/W_{NIPAAm}$			$W_{AAc}/W_{NIPAAm}$	$M_{AAc}/M_{NIPAAm}$
60/40		68	55/45	97/3
80/20		66	72/28	99/1

The synthesis of the graft copolymer NIPAAm-g-AAc by the  
 5 copolymerization method is represented schematically below.



## 2. Conjugation Method

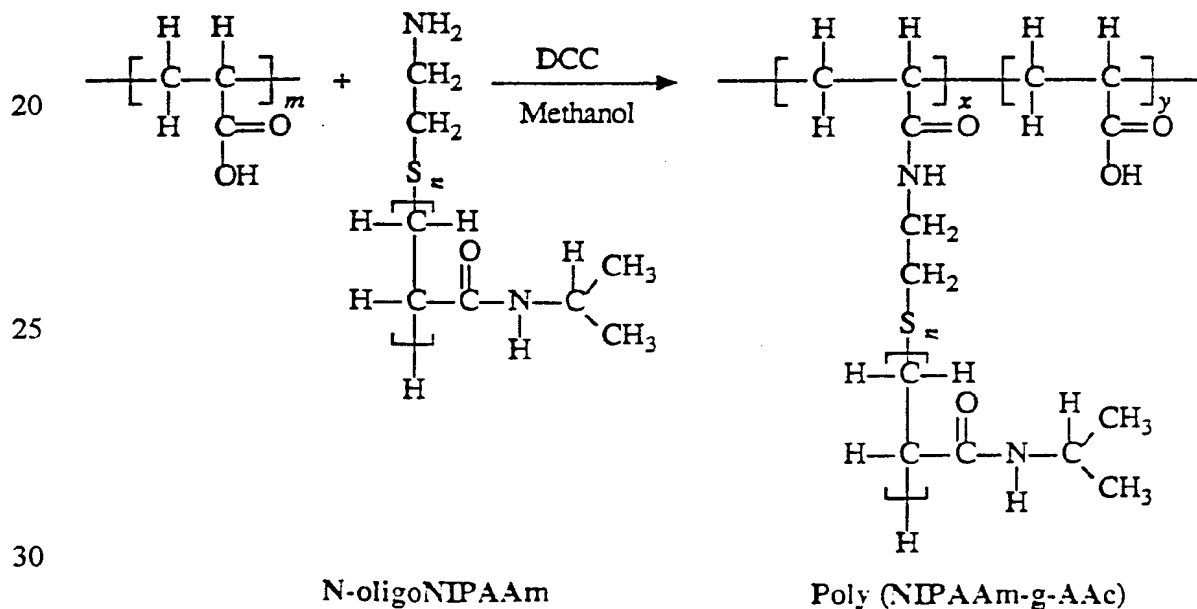
The graft copolymer of NIPAAm-g-AAc was synthesized by reaction of the amino group of the amino-terminated oligoNIPAAm with the carboxyl groups on the polyAAc backbone. In a representative reaction, amide bond formation was achieved by treatment of polyAAc (MW 250,000) and amino-terminated oligoNIPAAm (MW 3300) with dicyclohexylcarbodiimide in methanol at room temperature for 24 hours. The product graft copolymer was isolated by precipitation into methyl ethyl ketone, and further purified by reprecipitation into tetrahydrofuran. The results of the conjugation are presented below in Table 5.

Table 5: Conjugation of NIPAAm to PolyAAc

NIPAAm in Feed		Yield	NIPAAm in Copolymer <sup>a</sup>	
mole%	wt%		mole%	wt%
0.5	20	83	0.5	19
0.7	25	78	0.7	24
0.9	30	93	0.9	29
2.1	50	91	2.0	49

<sup>a</sup>Composition of NIPAAm was determined by back titration of the polyAAc component.

The synthesis of the graft copolymer NIPAAm-g-AAc by the conjugation method is represented schematically below.



## B. Temperature-Sensitive Behavior of the Graft Copolymers

The thermal-sensitivity of the graft copolymers prepared by copolymerization and conjugation exhibit similar temperature sensitivity. The graft copolymers prepared by direct conjugation with 20% to 50% NIPAAm demonstrate phase separation between 30°C and 35°C and are most appropriate as vehicles for drug delivery. The temperature-sensitive behavior of the graft copolymers NIPAAm-g-AAc is presented in Figure 3. The graft copolymer compositions begin to phase separate around 32°C and their response to temperature is rather broad due to the influence of the backbone COO<sup>-</sup>Na<sup>+</sup> moieties.

## C. Drug Loading and Release from the Graft Copolymers

### 1. Drug Loading

Graft copolymer drug loading was performed as described generally in Example 1C1. Solution of 0.5 g of the graft copolymer and 5.0 mg of timolol maleate in 8 ml methanol was precipitated into 800 mL of diethyl ether. White, sphere-like particles of the graft copolymer with an average 2-3 mm diameter were obtained. The percent recovery was 92% with 1 wt% of drug loaded. The material was ground into ca. 20-40µ particles for the drug release experiment.

### 2. Drug Release

A suspension of 40 mg graft copolymer NIPAAm-g-AAc/timolol mixture in 40 mL of PBS buffer was prepared. As described above in Example 1C2, the amount of drug released from the complex was determined as a function of time by determining the absorbance of the solution. The results of the drug release at 34°C and 37°C are presented in Figures 4 and 5, respectively.

As shown in Figure 4, drug release from graft copolymers is slower than from particles of random copolymers with similar compositions at 34°C. Increasing the temperature of the release medium to 37°C (Figure 5) slows down the release rate from the graft copolymers but not the release rate from the random copolymers. The results indicate that the increased hydrophobicity of the graft chains contributes to the slower release of drug.

Alternatively, copolymer dissolution and drug release may be determined simultaneously by casting the copolymer-drug mixture on a glass disc. In this method, a copolymer-drug mixture is cast onto a glass disc forming a film. The coated glass disc is then suspended in an appropriate medium such as phosphate buffered saline, pH 7.4, or distilled water. The temperature of the drug released into the medium may also be controlled to investigate temperature effects on dissolution and drug release. The

method facilitates the determination of drug released by measurement of the absorbance of the medium over time as described above, and simultaneously permits the determination of the amount of copolymer-drug mixture dissolved by measuring the weight of the film cast onto the hanging glass disc.

5           The results for drug release and dissolution for graft copolymer-timolol mixtures determined by the film cast on glass disc method are presented in Figures 6 and 7. Figure 6 illustrates the effect on drug release of MW of oligoNIPAAm used in the graft copolymers prepared as described above. Figure 7 illustrates the difference in the rates of release and dissolution for a graft copolymer NIPAAm-g-AAc (30% weight  
10 NIPAAm).

Figure 8 compares the effect of polymer structure on the rate of release of timolol from various polymer-drug cast films. The rate of release of timolol from homopolyAAc (molecular weight 250,000) is compared to different polymer-drug mixtures each containing 30 weight percent NIPAAm (i.e., random copolymer, graft  
15 copolymer, and a physical mixture of homopolyNIPAAm and homopolyAAc). The results demonstrate that release from the random copolymer is essentially complete within about 5 minutes while release from the graft copolymer is the most prolonged, nearly complete release taking about 20 minutes. Drug release from the physical mixture of homopolyNIAPPa and homopolyAAc was comparable to the rate of release  
20 from homopolyAAc, indicating that the physical mixture of temperature-sensitive and pH-sensitive homopolymers is no more effective than the use of the pH-sensitive homopolymer alone and significantly less effective than the corresponding graft copolymer.

25

### Example 3

#### Environmentally-Sensitive Graft Copolymers Comprising Temperature-Sensitive Copolymer and pH-Sensitive Homopolymer Components

In this example, the synthesis and characterization, temperature-sensitive  
30 behavior, and drug loading and drug release properties of graft copolymers comprising a temperature-sensitive copolymer component and a pH-sensitive homopolymer component is described. Two general embodiments are possible. The graft copolymer may possess a pH-sensitive polymer backbone with one or more pendant temperature-sensitive polymer components. Alternatively, the graft copolymer may have a  
35 temperature-sensitive polymer backbone with one or more pendant pH-sensitive polymer components. This example is directed to a graft copolymer with a pH-sensitive homopolymer backbone with pendant temperature-sensitive copolymer components.

A. Synthesis and Characterization of Graft Copolymers NIPAAm-BMA-g-AAc

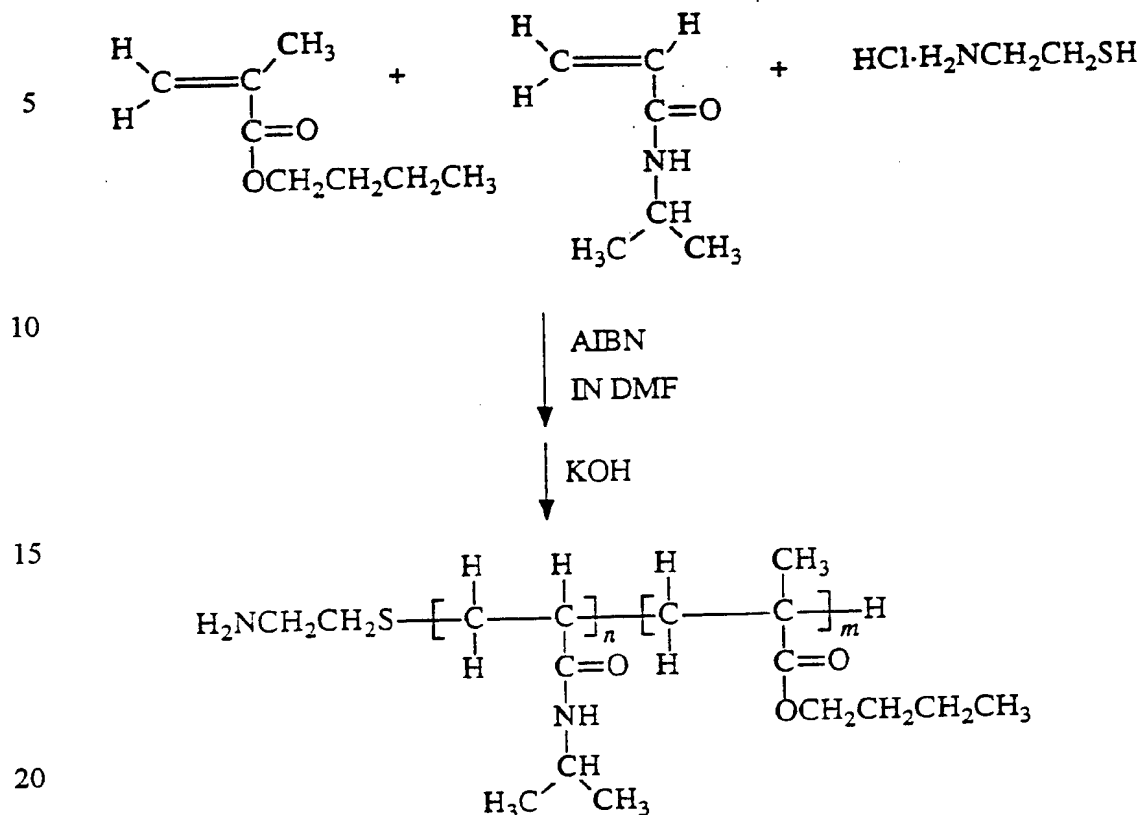
Graft copolymers (NIPAAm-BMA-g-AAc) comprising a temperature-sensitive copolymer component (NIPAAm-BMA) and a pH-sensitive homopolymer component (AAc) were synthesized from oligomers of NIPAAm-BMA and AAc. The graft copolymers were synthesized by covalently coupling an amino-terminated NIPAAm-BMA oligomer (see 1. below) to one or more carboxyl groups on the polyAAc backbone (see 3. below).

10           1. Synthesis of Amino-Terminated Co-oligo(NIPAAm-BMA)

Copolymerization of NIPAAm with a more hydrophobic monomer produces a copolymer with a lower LCST (cloud point) than the homopolymer polyNIPAAm. A co-oligomer with a lower LCST was synthesized by copolymerization of NIPAAm with a more hydrophobic comonomer, butylmethacrylate (BMA) in the presence of chain transfer reagent, 2-aminoethanethiol hydrochloride (AET-HCl) to obtain an amino-terminated co-oligomer NIPAAm-BMA. The co-oligomer was then grafted onto polyAAc.

In a representative synthesis, 3 mole% of BMA and 97 mole% of NIPAAm were charged with the molar ratio of monomer to initiator (AIBN) to chain transfer reagent (AET-HCl) of 100:1:5. 40 mL of DMF was used as solvent and the polymerization was performed at 60°C for 1 hour. The co-oligomer thus formed was recovered by precipitating into ether. The yield was 45% and the number average molecular weight of the co-oligomer determined by vapor pressure osmometry (VPO) was 3100. The BMA composition in the co-oligomer was determined to be 4 mole% by <sup>1</sup>H-NMR. The synthesis of co-oligomer NIPAAm-BMA is represented schematically below.





## 2. Determination of LCST of the Co-Oligomer NIPAAm-BMA

25 The LCST of the co-oligomer was spectroscopically measured at 500 nm using a 0.2% polymer solution in either pure water or PBS buffer, pH 7.4, as described above in Example 1B. The results are presented in Figures 9 and 10, respectively.

Referring to Figures 9 and 10, the co-oligomer shows a phase transition in pure water at 30°C, ca. 4°C lower than the oligoNIPAAm, and yet retains the same sharp response. In PBS buffer, the co-oligomer shows an even lower phase transition at 24°C, ca. 5°C lower than oligoNIPAAm. The lower phase transition for the co-oligomer in PBS as compared to water is believed to be due to a salt effect. The introduction of BMA comonomer units into the oligoNIPAAm provides a co-oligomer NIPAAm-BMA with a lower LCST (cloud point) than oligoNIPAAm. The 4°C-5°C difference in the LCST of the co-oligomer NIPAAm-BMA compared oligomer NIPAAm provides for increased versatility in the temperature-sensitive polymer component of the graft copolymer of the present invention.

### 3. Synthesis of Graft Copolymer of Co-oligo NIPAAm-BMA-g-AAc

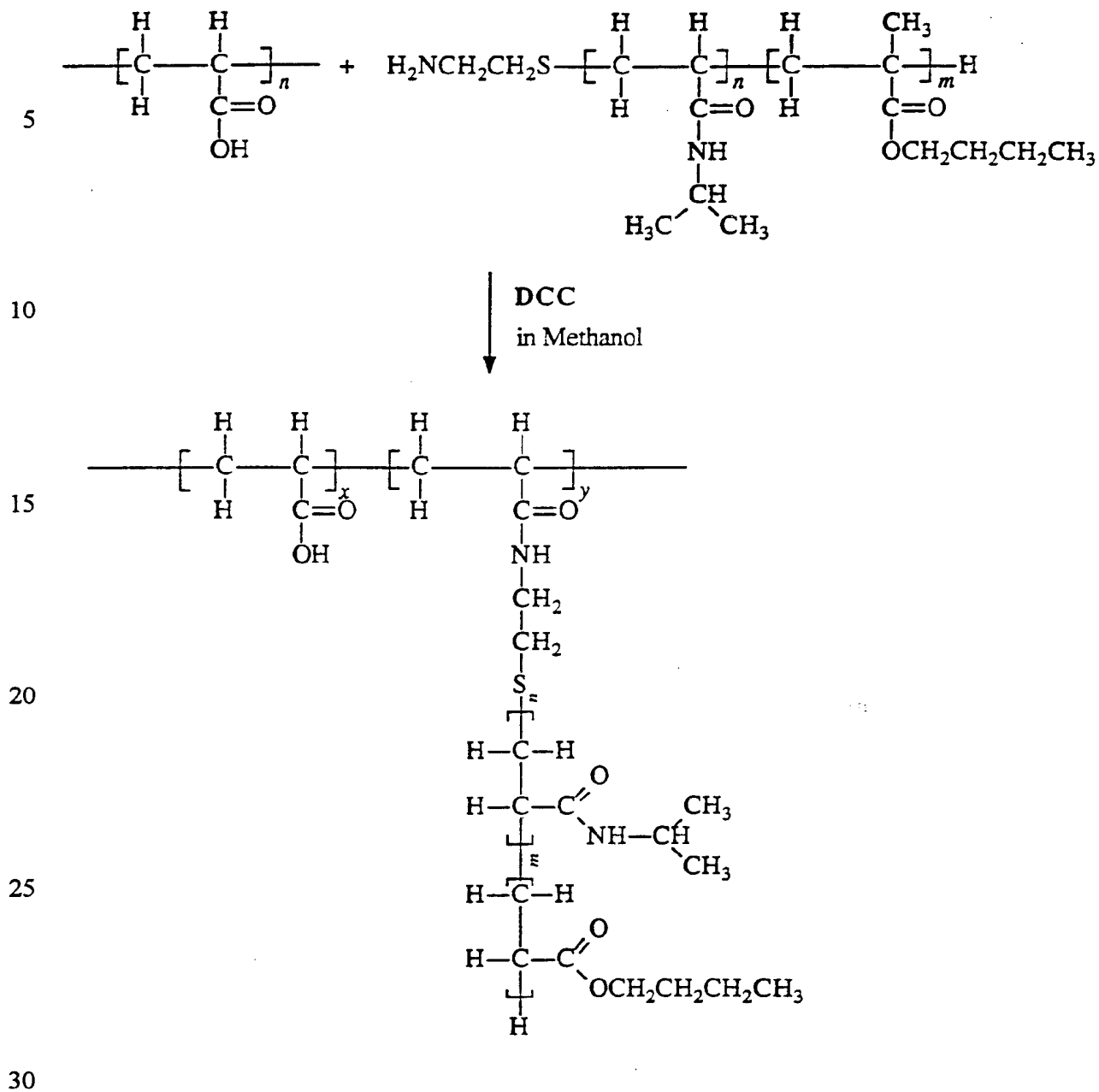
The graft copolymer of co-oligo[NIPAAm-BMA]-g-AAc was synthesized by reaction of the amino group of the amino-terminated co-oligomer NIPAAm-BMA with the carboxyl group(s) on the polyAAc backbone. Amide bond formation was achieved in the presence of dicyclohexylcarbodiimide (DCC) at room temperature for 24 hours. The weight ratio of polyAAc to co-oligomer used for the reaction was 1, i.e., 50/50 (wt/wt) varied from 50/50 to 95/5 (wt/wt). The graft copolymer was recovered in 75%-90% yield by precipitation into tetrahydrofuran (THF).

Table 6: Graft Copolymer Synthesis Results

Sample No.	Co-oligomer in feed in wt%	Yield	Co-oligomer in copolymer <sup>a</sup> wt%
1	50	91	45.5
2	20	80	19.0
3	30	77	28.0
4	10	74	8.9
5	5	82	4.5

<sup>a</sup>Compositions of co-oligomer in the graft copolymer was determined by back titration of the polyAAc component.

The synthesis of graft copolymers (NIPAAm-BMA)-g-AAc is represented schematically below.



### B. Temperature-Sensitive Behavior of the Graft Copolymers

The phase transition behavior of the graft copolymer NIPAAm-BMA-g-AAc was determined as described above in Example 1B. The phase transition data for the graft copolymer (NIPAAm-BMA)-g-AAc, the co-oligomer NIPAAm-BMA, and homopolyAAc are presented in Figure 11. Referring to Figure 11, the graft copolymer

- starts its phase transition in PBS at 28°C and at 34°C the phase transition is almost complete. The thermally-induced phase transition temperature for the above-described graft copolymer is significantly lowered by the introduction of hydrophobic comonomer units (BMA) into the oligoNIPAAm. At eye temperature (34°C), the graft co-oligomer chain becomes sufficiently hydrophobic to significantly reduce the drug release rate.

### C. Drug Loading and Release from Graft Copolymers

#### 1. Drug Loading

- Graft copolymer drug loading was performed as described generally in Example 1C1. A solution of 0.5 g of the graft copolymer and 5.0 mg of timolol-maleate in 8 ml methanol was precipitated into 800 mL of diethyl ether. White, sphere-like particles of the graft copolymer with an average 2-3 mm diameter were obtained. The percent recovery was 92% with 1 wt% of drug loaded. The material was ground into ca. 10-20 $\mu$  particles for the drug release experiment.

#### 2. Drug Release

- A suspension of 40 mg graft copolymer (NIPAAm-BMA)-g-AAc/drug mixture in 40 mL of PBS buffer was prepared. As described above in Example 1C2, the amount of drug released from the mixture was determined as a function of time by determining the absorbance of the solution. The results of the drug release are presented in Figure 12. For comparison, the drug release data for graft copolymer NIPAAm-g-AAc and random copolymer NIPAAm-AAC is presented in Figure 5.

- Referring to Figures 5 and 12, complete release of the drug from graft copolymer poly([NIPAAm-BMA]-g-AAc) requires 80 to 90 minutes, while complete release from the graft copolymers which have pure oligoNIPAAm as the graft component requires only about 20 minutes. The conclusion is that a more hydrophobic grafted oligomer provides for slower release rates. By increasing the hydrophobicity of the graft copolymer, the drug release rate is reduced significantly compared to polyAAc. Graft copolymers with less than 20% by weight co-oligomer are erodible and show a reduced rate of drug release. Graft copolymers with greater than 20% by weight co-oligomer also significantly reduce the drug release rate, but these copolymers are not erodible.

- The drug release from copolymer-drug mixture films cast on glass disc is presented in Figure 13. Figure 13 compares the rates of release of timolol from cast films of drug complexes of graft copolymers [NIPAAm-BMA]-g-AAc of varying co-oligomer NIPAAm-BMA content with homopoly AAC. The data presented compares drug release into phosphate buffered saline (pH 7.4) at 34°C for copolymers derived

from homopolyAAc with molecular weight 250,000 and cooligomer NIPAAm-BMA with molecular weight 3,100. The homopolyAAc reference had a molecular weight of 250,000.

The introduction of hydrophobic component units, BMA, into oligo NIPAAm lowers the thermally-induced phase transition temperature. As shown in Figure 13, at physiologic temperature and pH, the cooligomer chain, NIPAAm-BMA, imparts hydrophobicity to the graft copolymer sufficient to significantly reduce the rate of drug release compared to homopolyAAc. However, the graft copolymers containing 20% or more cooligomer NIPAAm-BMA are too hydrophobic and therefore not erodible under the above conditions of drug release. The graft copolymers containing less than 20% cooligomer NIPAAm-BMA (i.e., 5% and 10% cooligomer) do erode and provide drug release over a prolonged period compared to homopolyAAc. Moreover, these grafted copolymers with lower content of pendant temperature-sensitive polymer components maintain bioadhesive properties sufficient to render these graft copolymer effective not only with respect to drug release, but also in relation to prolonged residence time in the treatment area. Accordingly, graft copolymers [NIPAAm-BMA]-g-AAc with cooligomer NIPAAm-BMA content between 5% and 20% are suitable for sustained release drug delivery and graft copolymers with cooligomer content between 10% and 15% are preferred.

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#### Example 4

##### Environmentally-Sensitive Hydrogels Comprising Temperature Sensitive and pH-Sensitive Homopolymer Components

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In this example, the synthesis and characterization, swelling, and drug loading and release properties of lightly cross-linked graft copolymers comprising a carboxylic acid-containing polymer backbone and with pendant temperature-sensitive polymer components. The cross-linked carboxylic acid-containing polymer was prepared followed by grafting of the temperature-sensitive polymer.

30

#### A. Synthesis and Characterization of Cross-linked Hydrogel NIPAAm-g-AAc

A series of hydrogels was prepared from AAc monomer solutions (40 weight % of AAc monomer) with a fixed amount of initiator, ammonium persulfate, and various amounts of cross-linker, ethylene glycol dimethylacrylate (EGDMA), in distilled water. The concentration of EGDMA was varied from 0.3%, 0.5%, 1.0%, to 2.0% by weight based on total AAc monomer. In a representative synthesis, the solution was

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degassed with nitrogen and injected into the 1.5 mm space between two glass plates. Polymerization was continued for 17 hours at 60°C. The resulting hydrogel sheet was washed by suspending the sheet in an ethanol bath for 48 hours. Disc-shaped hydrogels were obtained by cutting the gel sheet with a cork borer (15 mm diameter), followed by  
5 drying for 48 hours in air and for 24 hours under vacuum.

To graft the temperature-sensitive polymer component to the pH-sensitive cross-linked hydrogel, the dried gels prepared as described above, were swollen in methanol solutions containing varying amounts of amino-terminated NIPAAm, molecular weight 3,300 g/mol (solution concentrations from 0.65 g/L to  
10 32.89 g/L). The swelling was carried out at room temperature for 48 hours. The uptake of amino-terminated NIPAAm by the gels was calculated from the equilibrium swollen volume of the gel. The hydrogel absorbed amino-terminated NIPAAm was then grafted (covalently coupled) to the polyAAc backbone by immersion of the hydrogel into a methanol solution containing a three-fold excess (relative to the amino-terminated  
15 NIPAAm) of coupling agent, dicyclohexylcarbodiimide (DCC). The coupling was carried out for 48 hours at room temperature. The resulting grafted hydrogel was washed with methanol and dried for 48 hours in air and for 24 hours under vacuum. The synthesis of the graft copolymer hydrogels is represented schematically in Figure 14. The degree of grafting was determined by comparing the dry weight of the pure  
20 polyAAc hydrogel with the product grafted hydrogel. The degree of grafting is represented graphically in Figure 15.

Generally, the percent grafting increased linearly with concentration of amino-terminated NIPAAm in solution with the initial reaction rate of the grafting being higher as the density of the cross-linking was decreased. A plateau of grafting level was  
25 reached for all samples.

#### B. Swelling of the Grafted Hydrogels

To determine the swelling characteristics of the grafted hydrogels prepared as described above, grafted hydrogel discs were incubated in 0.05 M phosphate  
30 buffer solution containing 0.15 M sodium chloride at pH 7.4 at 34°C. A Lab-Line water shaker-bath was used for temperature control. In a representative determination, a solution of the grafted hydrogel was shaken at 150 rpm and the swelling weights of the hydrogels measured by weighing the sample at various times. The weights were measured after removing the gel from the buffer, and blotting adhered water with  
35 weighing paper. The swelling ratios were determined as the swollen weight/dried weight (Wt/Wo) and are presented in Figure 16.

At high cross-link density, the greater the amount of grafted NIPAAm to the polyAAc, the slower the initial swelling rate. The slower rate is probably due to the increased hydrophobicity imparted to the graft hydrogel by the NIPAAm pendant chains. At low cross-link density, the uptake rates are more rapid, and the effect of grafting on these rates was less important.

C. Drug Loading and Release from Grafted Hydrogels

1. Drug Loading

Timolol hydrogen maleate was loaded into the graft copolymer hydrogel by swelling the hydrogel in the drug-methanol solution at room temperature for 24 hours. The drug-loaded hydrogels were dried for 24 hours in air and for 24 hours under vacuum. The drug loading was determined to be 2% by weight of the dried copolymer hydrogel.

2. Drug Release

Graft copolymer hydrogel drug release was determined as generally described in Example 1C2. The initial drug release rates are dependent upon the graft level and the length of the graft chains. The higher the graft level and/or the shorter the length of the graft chains, the slower the drug releases from the hydrogel. The release of drug from the graft copolymer hydrogel is presented in Figure 17. As shown in Figure 17, the greater degree of grafting or the lower the molecular weight of the pendant oligoNIPAAm, the slower the rate of drug release from the hydrogel.

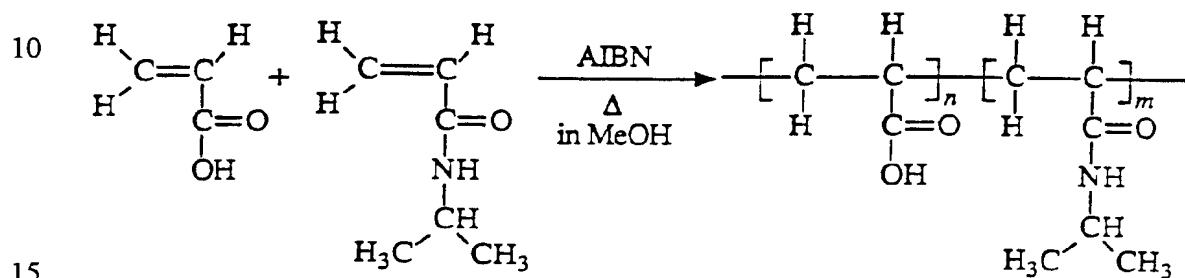
Example 5

Random Copolymers Derived From Copolymerization of NIPAAm and AAc

For purposes of comparison to the environmentally-sensitive block and graft copolymers of the present invention, this example describes the synthesis, characterization, temperature-sensitive behavior, and drug loading and release properties of random copolymers derived from the polymerization of N-isopropylacrylamide (NIPAAm) and acrylic acid (AAc).

A. Synthesis and Characterization of Random Copolymers of NIPAAm and AA

Random copolymers were synthesized by copolymerization of N-isopropylacrylamide and acrylic acid by standard radical polymerization procedures. Various random copolymers were prepared by varying the mole percent of NIPAAm  
 5 monomer in the polymerization reaction. The synthesis of the random copolymer is represented schematically below.



20 The synthetic results and the temperature-sensitive behavior of the random copolymers is summarized in Table 7.



**Table 7. Synthesis and Temperature-Sensitive Properties of Random Copolymers**

<sup>I</sup> NIPAAm (in monomer)	Polym. Time	Conversion	<sup>F</sup> NIPAAm <sup>a</sup> (in copolymers)		<sup>M</sup> w <sup>b</sup> (x 10 <sup>-5</sup> )	LCST (°C)	
			wt%	mol%		pH 4.0	pH 7.4
100	20.0	76.3	100	100	-	30.7	32.6
92	2.3	55.0	93	89	-	32.2	64.1
85	2.3	45.0	88	82	-	34.6	>95
72	4.0	41.0	79	71	2.01	38.1	>95
49	3.0	35.7	67	56	2.01	61.0	>95
30	3.0	26.7	57	46	2.01	>95	>95
10	4.0	18.3	46	35	1.75	>95	>95
7	6.0	41.2	38	28	1.75	>95	>95
3	6.5	59.5	33	24	1.70	>95	>95

\* Monomer concentration [NIPAAm + AAc] = 8.0% (w/v); concentration of initiator [AIBN] = 0.02% (w/v); solvent, methanol; polymerization temperature, 60 °C;

<sup>a</sup> The composition of NIPAAm in copolymers was determined by conductometric titration with 0.1 N NaOH, which detects the carboxyl group from AAc monomer unit;

<sup>b</sup> The molecular weight of the copolymers was determined by GPC using polyacrylamide as standard, water as an eluent.

#### 5 B. Temperature-Sensitive Behavior of Random Copolymers

The temperature-sensitive behavior of the random copolymers prepared as described above was investigated as generally described in Example 1B. The LCSTs for the random copolymers are summarized in Table 7 and the temperature-sensitive behavior for a random copolymer comprising 89 mole percent NIPAAm is illustrated in Figure 18. The results show that random copolymers of NIPAAm and AAc with mole percents of AAc greater than about 10% do not undergo thermal phase separations at physiological pH (pH 7.4) or physiological temperature (34°C). As illustrated in Figure 18, the random copolymer does undergo a sharp phase transition at 31°C at pH 4.0 and at 64°C at pH 7.4.

Random copolymers as described above are ineffective in the practice of the present invention because the mole percent of AAc present in the random copolymer to achieve the requisite temperature-sensitivity reduces the bioadhesiveness of the copolymer below that effective for sustained drug release. Furthermore, for those random copolymers which do undergo phase transitions, either the temperature required for the phase transition or the pH is well outside physiological conditions.

### C. Drug Loading and Release from Random Copolymers

#### 1. Drug Loading

Generally, random copolymer-drug complexes were prepared as described in Example 1C1.

The random copolymer-drug particles were prepared by dissolving 0.5 g of polymer and 5 mg of timolol (feed ratio is 1 wt%) in 10 mL of methanol and then precipitating into 500 mL of diethyl ether. The precipitate was then dried under vacuum overnight. The drug content in the particles were determined by dissolving the particles to form a solution, and spectroscopically measuring the absorbance of the drug in the solution at 294 nm. The results of drug loading for the random copolymer prepared as described above and the graft copolymers prepared as described in Example 3 are presented in Table 8.

Table 8.

Comparison of Random and Graft Copolymer Drug Loading

Polymer:	Random copolymer			Graft copolymer		
wt% NIPAAm in copolymer	26	32	39	20	30	50
Polymer added (g)	0.5	0.5	0.5	0.5	0.5	0.5
Drug added (mg)	5.0	5.0	5.0	5.0	5.0	5.0
Polymer recovery (% w/w)	94	94	94	74	90	90
Drug loaded (mg/g Polymer)	9.4	9.2	9.1	9.9	10.0	10.8

#### 2. Drug Release

Generally, the measurement of drug released from the random copolymer-drug particles was determined as described in Example 1C2. The drug release results for the various random copolymers are compared to graft copolymers of similar composition at 34°C and 37°C in Figures 4 and 5, respectively. The results show that drug release from the random copolymers at 34°C is about twice as fast as release from the graft copolymers. For the random copolymers, the drug is completely released within 10 minutes. The results at 37°C are qualitatively similar to those at 34°C, although complete release of drug takes about 24 minutes.

Example 6

Environmentally-Sensitive Graft Copolymers Comprising  
Temperature-Sensitive Copolymer and pH-Sensitive Homopolymer Components

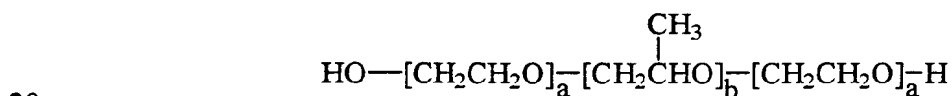
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In this example, the synthesis and characterization, temperature-sensitive behavior, and drug loading and drug release properties of graft copolymers comprising temperature-sensitive copolymer and pH-sensitive homopolymer components are described. Specifically, the temperature-sensitive copolymer component is a block copolymer of ethylene oxide and propylene oxide ("EO/PO/EO"), and the pH-sensitive homopolymer component is a homopolymer of acrylic acid (AAc). The AAc homopolymer was utilized as the backbone of the graft copolymer.

A. Synthesis and Characterization of Graft Copolymers of EO/PO/EO-g-AAc  
1. Synthesis of Amino-Terminal Block Copolymer of EO/PO/EO

15

Block copolymers of EO/PO/EO are commercially available as surfactants from BASF-Wyandotte Corp. (Wyandotte, Michigan) and sold under the tradename Pluronic.<sup>®</sup> Such block copolymers of EO/PO/EO have the following general structure:



20

where the ratio of a:b:a varies as illustrated in the following Table 9:

Table 9  
Block Copolymers of EO/PO/EO

25	Pluronic <sup>®</sup>	EO/PO/EO Ratio	Total M.W. (avg.)
	L-61	4/30/4	2,000
	L-81	7/38/7	2,750
	L-92	10/50/10	3650
	L-122	13/69/13	5,000

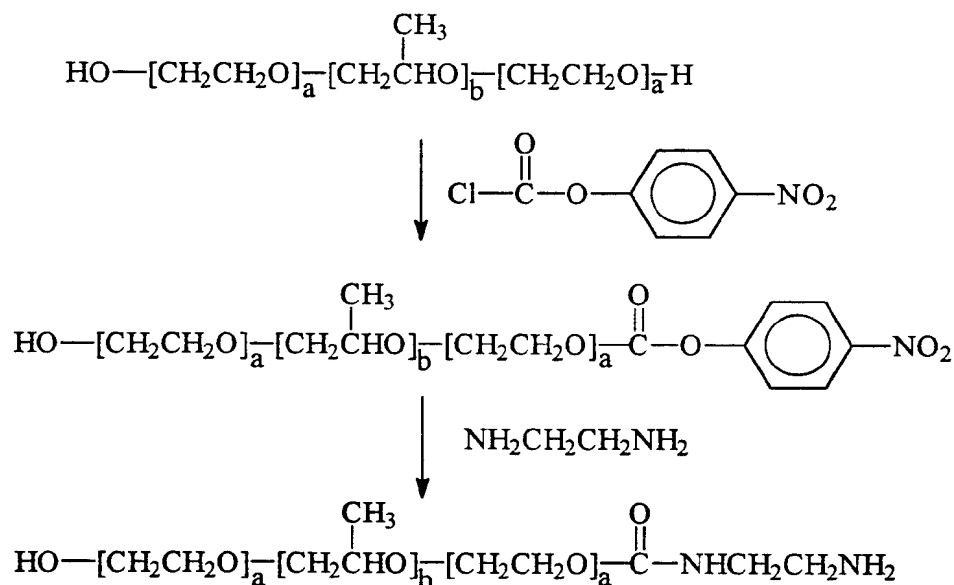
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The LCST of Pluronic<sup>®</sup> L-122 was evaluated by measuring absorbance as a function of temperature. Specifically, a 0.5% by weight solution of L-122 (PBS buffer, pH 7.4) was prepared, and light absorbance (at 500 nm) was measured at temperatures ranging from 15°C to 30°C. The LCST of the L-122 solution was found to be 26°C, and the results of this experiment are presented in Figure 19.

35

The above block copolymers of EO/PO/EO were then derivatized to yield a reactive amino-terminal by a two step reaction. First, 20g of L-122 (4 mmole) was reacted with 1.0g (5 mmole) of 4-nitrophenyl chloroformate in methyl chloride in the presence of triethylamine at room temperature for 4 hours to yield a 4-nitrophenyl  
 5 formed-derivatized intermediate. This intermediate was recovered by extraction using petroleum ether for three times, resulting in 14 g of product with a yield of 72% by weight. In the second step, 10 g (2 mmole) of the intermediate was reacted with 0.36 g (6 mmole) of diaminoethylene in methylene chloride at room temperature overnight. The amino-terminated L-122 derivative was recovered by extraction with petroleum  
 10 ether for three times, dialysis against distilled water using a membrane with MW cut-off of 3500 for three days, and evaporated of water to obtain the product (8.8 g, yield of 88% by weight). Functionality of the amino-terminated derivative was determined by titration as  $0.91 \pm 0.1$ .

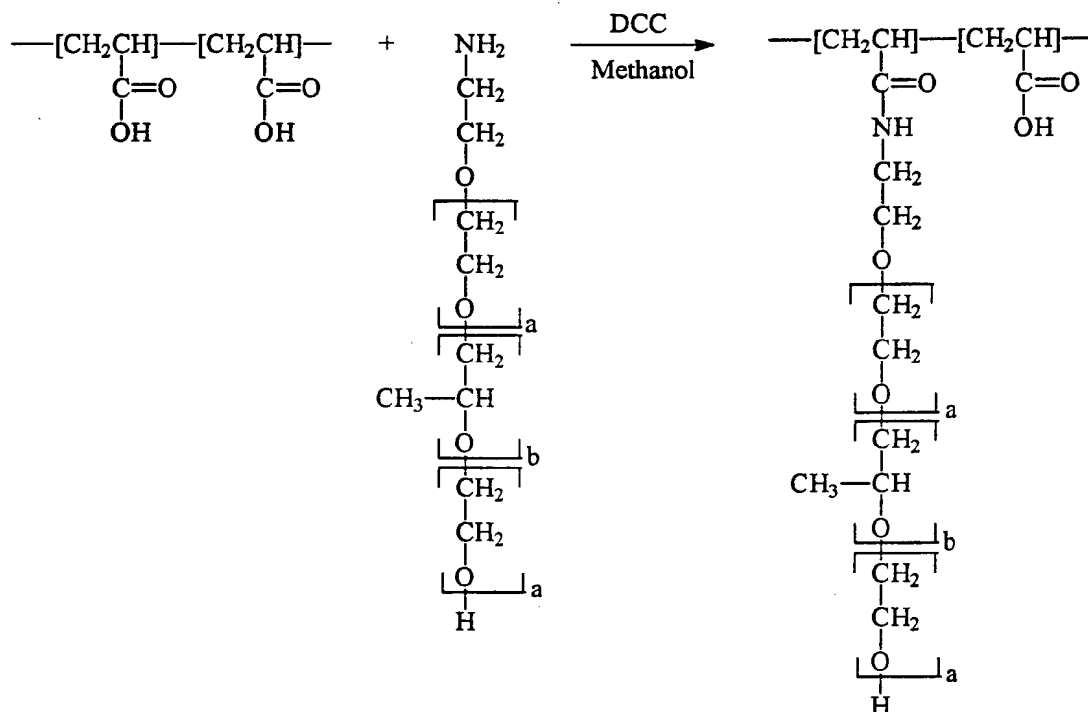
The other block copolymers of EO/PO/EO were similarly derivatized to  
 15 yield a reactive amino-terminal by the reaction scheme illustrated below.



## 2. Synthesis of Graft Copolymers of EO/PO/EO-g-AAc

20 Graft copolymers of EO/PO/EO-g-AAc were prepared by coupling the reactive amino-terminals of the derivatized block copolymers of EO/PO/EO onto the homopolymer backbone of AAc. Specifically, reaction between the amino group of the amino-terminated EO/PO/EO derivative and a carboxyl group of AAc, in the presence of dicyclohexyl carbodiimide (DCC), resulted in amide bond formation. The reaction

was carried out in methanol (100 mL) at room temperature for 24 hours, with a mole ratio of the block copolymer of EO/PO/EO to DCC of 2:1. Synthesis of the graft copolymers of EO/PO/EO-g-AAc is represented schematically below:



5

The resulting graft copolymers were recovered from the reaction solution by precipitation into THF or diethylether. Characterization of the graft copolymers was performed using GPC with Waters 500Å, 10<sup>3</sup>Å and 10<sup>4</sup>Å Ultrastylene® columns, DMF as mobile phase, at 40°C and an elution rate of 0.7 mL/min.

10

Graft copolymers were prepared at varying ratios of components, and using various block copolymers of EO/PO/EO as identified in Table 10.

Table 10

15

Graft Copolymers of Block EO/PO/EO and PolyAAc

Pluronic®	Pluronic®/PolyAAc	Yield (%)
L-61	10/90(wt%)	79
L-61	20/80(wt%)	55
L-61	30/70(wt%)	86
L-92	30/70(wt%)	94
L-122	10/90(wt%)	80

20

L-122	20/80(wt%)	80
L-122	30/70(wt%)	68
L-122	40/60(wt%)	78
L-122	50/50(wt%)	65

5

#### B. Temperature-Sensitive Behavior of Graft Copolymers of EO/PO/EO-g-AAc

The graft copolymers of EO/PO/EO of this example form a translucent gel at approximately 32°C. Accordingly, rather than using an absorbance measurement for LCST, the solution-to-gel phase transition temperature was determined by measuring viscosity as a function of temperature by the following procedure.

A scintillation vial containing a stir bar was weighed, and 2.8 g of an aqueous solution containing 0.76% NaCl and 1.25% NaOH was added thereto. Next, 0.125 g of the L-122-30/70(wt%) graft copolymer was added, followed by 1.2 g of a 0.76% NaCl solution. The L-122-30/70(wt%) graft copolymer was dissolved by stirring the solution in an ice bath for about 2 hours, and then by keeping the scintillation vial in the refrigerator overnight. A sufficient amount of 1 N NaOH was added to the solution to yield a pH of 7.2. To this was added 0.05 g of 8.5% NaCl, and sufficient water was added to bring the solution to 5.0 g. The resulting solution contained 2.5% by weight of the L-122-30/70(wt%) graft copolymer, and had a pH of 7.2.

The viscosity of the solution was then measured at various temperatures ranging from 25°C to 40°C using a Brookfield DV III RV viscometer fitted with a CP-52 spindle. The temperature was controlled by circulating water from a constant temperature water bath through the jacket of the viscometer cup. About 0.6 ml of the solution was placed in the viscometer cup. The viscosity measurements were carried out at 0.1 rpm (shear rate 0.2/second) for 3 minutes at a fixed temperature. The viscosity value at the end of 3 minutes was recorded, and the results of these measurements are presented in Figure 20. As determined by this technique, the LCST of the L-122-30/70(wt%) graft copolymer was found to be 32°C at 25% of maximum viscosity.

#### C. Drug Loading and Release from Graft Copolymers of EO/PO/EO-g-AAc

Drug loading and release from the copolymer-drug mixture was determined by casting a film of a copolymer-drug mixture (containing 5% by weight timolol maleate) on a glass disk as disclosed in Example 1C2. In these experiments, the thickness of the films was ca. 150  $\mu$ , the diameter was ca. 0.54-0.58 mm, and the weight of each film was ca. 5 mg. The coated glass discs were suspended in PBS buffer (pH 7.4) at 34°C, and the amount of drug release was measured as a function of time. The results of this experiment are presented in Figures 21, 22 and 23.

Specifically, Figure 21 illustrates drug release from graft copolymers of EO/PO/EO-g-AAc at varying ratios of EO/PO/EO to AAc (*i.e.*, 70% AAc grafted with 30% L-61, 80% AAc grafted with 20% L-61, and 90% AAc grafted with 10% L-61). For comparison purposes, drug release from a homopolymer of AAc (*i.e.*, 100% AAc), as well as a physical mixture of 80% homopolymer AAc and 20% L-61, are also presented in Figure 21. In this example, graft copolymers of EO/PO/EO and AAc showed significantly retarded drug release profiles compared to the AAc homopolymer alone or the physical mixture of the same with L-61. Moreover, complete drug release was delayed to over 1 hour when the content of L-61 was 20% (or higher) compared to AAc.

Figure 22 illustrates drug release from graft copolymers utilizing L-122 as the block copolymer of EO/PO/EO. In this experiment, graft copolymers of L-122-g-AAc at ratios varying from 90% AAc/10% L-122 to 50% AAc/50% L-122 were employed. With 30% (or more) L-122 grafted to AAc, complete drug release time was more than 4 hours.

Lastly, Figure 23 illustrates the drug release properties associated with the use of different block copolymers of EO/PO/EO - that is, L-61, L-92 and L-122. Graft copolymers of 70% AAc and 30% L-61, L-92 or L-122 were tested. The block copolymer L-122, when grafted to the AAc backbone, resulted in a prolonged drug time of over four hours. In addition, a physical mixture of a temperature-sensitive polymer (such as the Pluronic® L-122) with a copolymer-drug mixture of this invention may, in certain instances, prolong drug release therefrom, and is within the scope of the present invention.

From the foregoing, it will be appreciated that, although specific embodiments of this invention have been described herein for the purposes of illustration, various modifications may be made without departing from the spirit and scope of the invention. Accordingly, the invention is not limited except by the appended claims.

### Claims

1. A graft copolymer comprising a backbone pH-sensitive polymer component with a pendant temperature-sensitive polymer component grafted thereto, wherein the graft copolymer has a lower solution critical temperature ranging from 20°C to 40°C measured at a pH between 6.0 to 8.0.
2. A graft copolymer comprising a backbone temperature-sensitive polymer component with a pendant pH-sensitive polymer component grafted thereto, wherein the graft copolymer has a lower solution critical temperature ranging from 20°C to 40°C measured at a pH between 6.0 to 8.0.
3. A block copolymer comprising a pH-sensitive polymer component and a temperature-sensitive polymer component joined thereto, wherein the block copolymer has a lower solution critical temperature ranging from 20°C to 40°C measured at a pH between 6.0 to 8.0.
4. The copolymer of any one of claims 1, 2 or 3 wherein the lower critical solution temperature is determined at a pH between 7.0 to 7.8.
5. The copolymer of any one of claims 1, 2 or 3 wherein the lower solution critical temperature ranges from 26°C to 34°C.
6. The copolymer of any one of claims 1, 2 or 3 wherein the lower solution critical temperature ranges from 28°C to 32°C.
7. The copolymer of any one of claims 1, 2 or 3 wherein the pH-sensitive polymer component comprises a carboxylic acid-containing polymer.
8. The copolymer of claim 7 wherein the carboxylic acid-containing polymer is derived from polymerizable carboxylic acids selected from the group consisting of acrylic acid, methacrylic acid, ethacrylic acid,  $\beta$ -methylacrylic acid, cis- $\alpha$ -methylacrylic acid, trans- $\alpha$ -methylcrotonic acid,  $\alpha$ -butylcrotonic acid,  $\alpha$ -phenylacrylic acid,  $\alpha$ -benzylacrylic acid,  $\alpha$ -cyclohexylacrylic acid,  $\beta$ -phenylacrylic acid, coumaric acid and umbellic acid.
9. The copolymer of claim 78 wherein the carboxylic acid-containing polymer is carboxymethylcellulose.



10. The copolymer of any one of claims 1, 2 or 3 wherein the pH-sensitive polymer component consists essentially of a homopolymer.
11. The copolymer of any one of claims 1, 2 or 3 wherein the pH-sensitive polymer component is a homopolymer.
12. The copolymer of claim 11 wherein the homopolymer is polyacrylic acid.
13. The copolymer of any one of claims 1, 2 or 3 wherein the pH-sensitive polymer component is a random or block copolymer.
14. The copolymer of any one of claims 1, 2 or 3 wherein the temperature-sensitive polymer component is a homopolymer.
15. The copolymer of claim 14 wherein the homopolymer is poly(N-isopropylacrylamide).
16. The copolymer of any one of claims 1, 2 or 3 wherein the temperature-sensitive polymer component is a random or block copolymer.
17. The copolymer of claim 16 wherein the temperature-sensitive polymer component is a random copolymer of N-isopropylacrylamide and butylmethacrylate.
18. The copolymer of claim 16 wherein the temperature sensitive polymer component is a block copolymer of ethylene oxide and propylene oxide.
19. The copolymer of any one of claims 1, 2 or 3 wherein the pH-sensitive polymer component is a homopolymer and the temperature-sensitive polymer component is a random or block copolymer.
20. The copolymer of any one of claims 1, 2 or 3 wherein the pH-sensitive polymer component is lightly cross-linked.
21. The copolymer of any one of claims 1, 2 or 3 wherein the temperature-sensitive polymer component is lightly cross-linked.

22. A graft copolymer-drug mixture comprising a drug and a graft copolymer, wherein the graft copolymer comprises a backbone pH-sensitive polymer component with a pendant temperature-sensitive polymer component grafted thereto.

23. A graft copolymer-drug mixture comprising a drug and a graft copolymer, wherein the graft copolymer comprises a backbone temperature-sensitive polymer component with a pendant pH-sensitive polymer component grafted thereto.

24. A block copolymer-drug mixture comprising a drug and a block copolymer, wherein the block copolymer comprises a pH-sensitive polymer component and a temperature-sensitive polymer component joined thereto.

25. The copolymer-drug mixture of any one of claims 22, 23 or 24 wherein the copolymer has a lower solution critical temperature ranging from 20°C to 40°C measured at a pH between 4.0 and 8.0.

26. The copolymer-drug mixture of any one of claims 22, 23 or 24 wherein the mixture is in the form of a solid particle.

27. The copolymer-drug mixture of claim 26 wherein the solid particle is suspended in a pharmaceutically acceptable carrier.

28. The copolymer-drug mixture of any one of claims 22, 23 or 24 wherein the mixture is formulated as a liquid, gel or ointment.

29. The copolymer-drug mixture of claim 28 wherein the mixture is formulated as a liquid which gels upon administration to a treatment area.

30. A method for administering a drug to a treatment area, comprising applying to the treatment area a copolymer-drug mixture of any one of claims 22, 23 or 24.

31. The method of claim 30 wherein the copolymer-drug mixture is applied in the form of a solid particle.

32. The method of claim 31 wherein the solid particle is applied as a suspension within a pharmaceutically acceptable carrier.

33. The method of claim 30 wherein the mixture is applied as a liquid, gel or ointment.

34. The method of claim 30 wherein the mixture is applied as a liquid which gels upon administration to the treatment area.

35. A graft copolymer hydrogel comprising a first backbone environmentally-sensitive polymer component with a second pendant environmentally-sensitive polymer component grafted thereto, wherein the first and second polymer components are each responsive to a different trigger.

36. A block copolymer hydrogel comprising a first environmentally-sensitive polymer component and a second environmenatlly-sensitive polymer component joined thereto, wherein the first and second polymer components are each responsive to a different trigger.

37. The hydrogel of any one of claims 35 or 36 comprising at least one polymer component responsive to a thermal trigger and at least one polymer comonent responsive to a pH trigger.

38. The hydrogel of any one of claims 35 or 36 comprising at least two polymer components responsive to thermal triggers and with different transition temperatures.

39. The hydrogel of any one of claims 35 or 36 comprising at least two polymer components responsive to pH triggers with different pH transition ranges.

40. The copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36 further comprising a solvent.

41. The copolymer or hydrogel of claim 40 wherein the solvent comprises at least 10% by weight a non-aqueous liquid.

42. The copolymer or hydrogel of claim 40 wherein the solvent comprises at least 99% by weight a non-aqueous liquid.

43. A method of absorbing a solvent or solution, comprising exposing the hydrogel of any one of claims 35 or 36 to the solvent or solution and allowing the hydrogel to swell.

44. The method of claim 43 wherein the solvent or solution comprises a material selected from the group consisting of urine, feces, water, blood, brine and an ionic water solution.

45. The method of claim 43 wherein the swelling ratio of the hydrogel is not less than 15.

46. A diaper where a superabsorbant component comprises the hydrogel of any one of claims 35 or 36.

47. A copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36 wherein the copolymer or hydrogel provides moisture to a treatment area.

48. A copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36 wherein the copolymer or hydrogel retains moisture at a treatment area.

49. A copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36 wherein the copolymer or hydrogel provides hydration to a treatment area.

50. A copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36 wherein at least one of the polymer components comprises a bioadhesive.

51. A cosmetic composition, a wound dressing, a pharmaceutical composition comprising a drug, an iontophoretic device, a monitoring electrode, an adhesive, a cream, a foam, a suppository, a tablet, a delivery gel, a device for nasal, vaginal, oral, ocular, rectal, dermal or otic delivery, or a laxative, comprising a copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36.

52. A device for vaginal delivery of a drug according to claim 51 wherein the drug is selected from a spermicide, ovacide, antimicrobial, antifungal, prostaglandin, and steroidal or nonsteroidal fertility agent.

53. A device for drug delivery according to claim 51 wherein the drug is contained in a medicinally inert matrix in the form of a three-dimensional structure having at least one surface portion.

54. The device of claim 53 wherein the three-dimensional structure is capsular in form and has a largest dimension of about 1 nanometer to about 5000 microns.

55. A system for control of reactive chemistry, separation of solution components, separation of ionic species, or control of chemomechanical work, comprising a copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36.

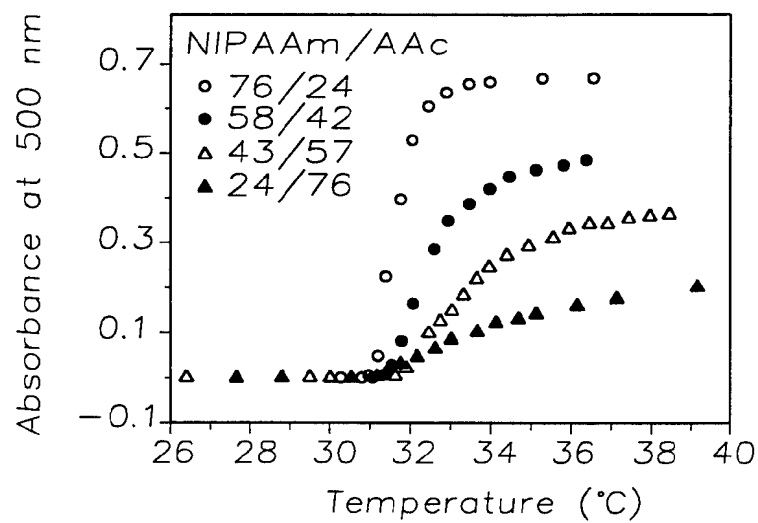
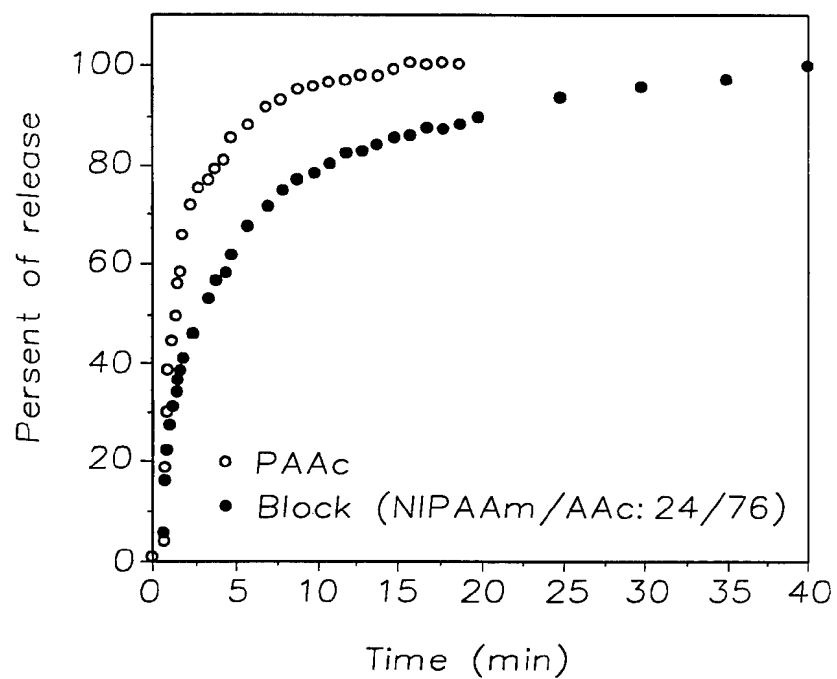
56. A system for control of viscosity or flow comprising a hydrogel of any one of claims 35 or 36.

57. A copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36 mixed with a polymer selected from a homopolymer, a random copolymer, a block copolymer and a graft copolymer.

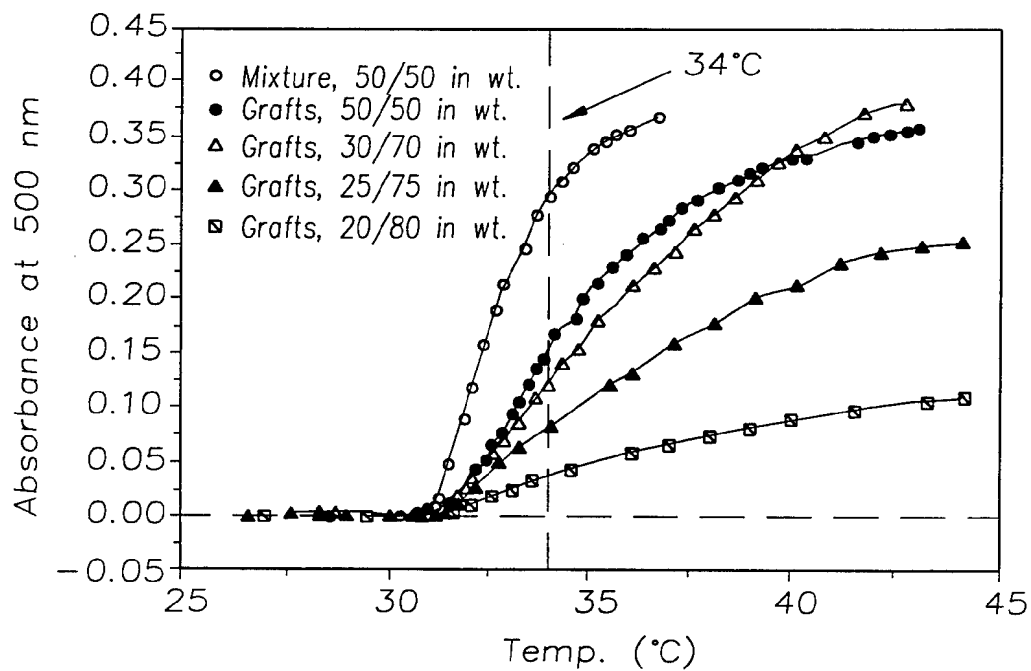
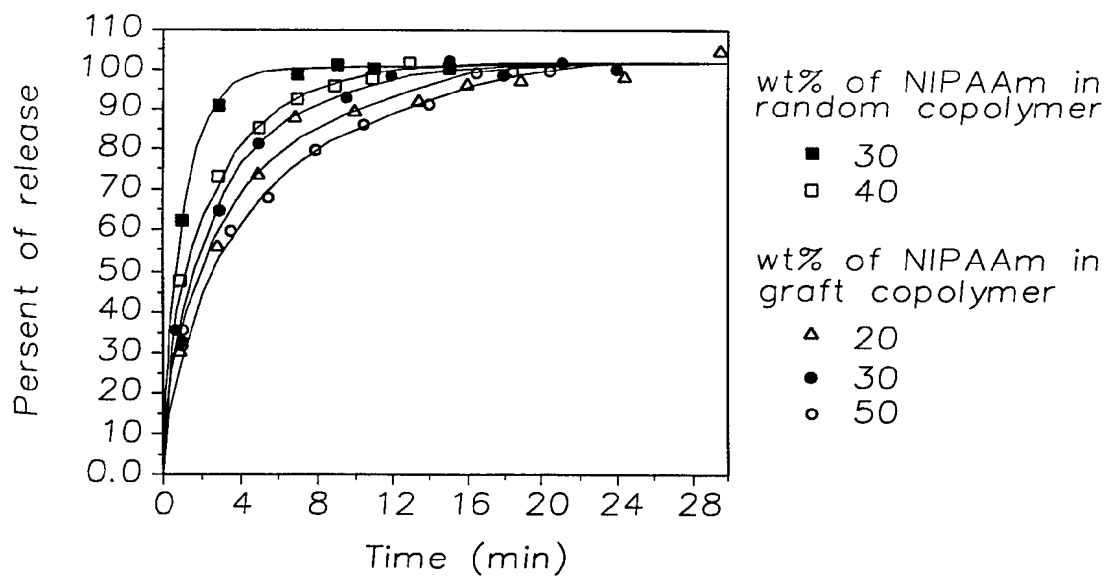
58. The copolymer or hydrogel of claim 57 wherein the polymer is a homopolymer of acrylic acid.

59. The copolymer or hydrogel of claim 57 wherein the polymer is a block copolymer of ethylene oxide and propylene oxide.

60. A pharmaceutical formulation for administering a drug to a treatment area, comprising the copolymer-drug mixture of any one of claims 22, 23 or 24, wherein the formulation is in the form of a liquid which gels upon administration to the treatment area.

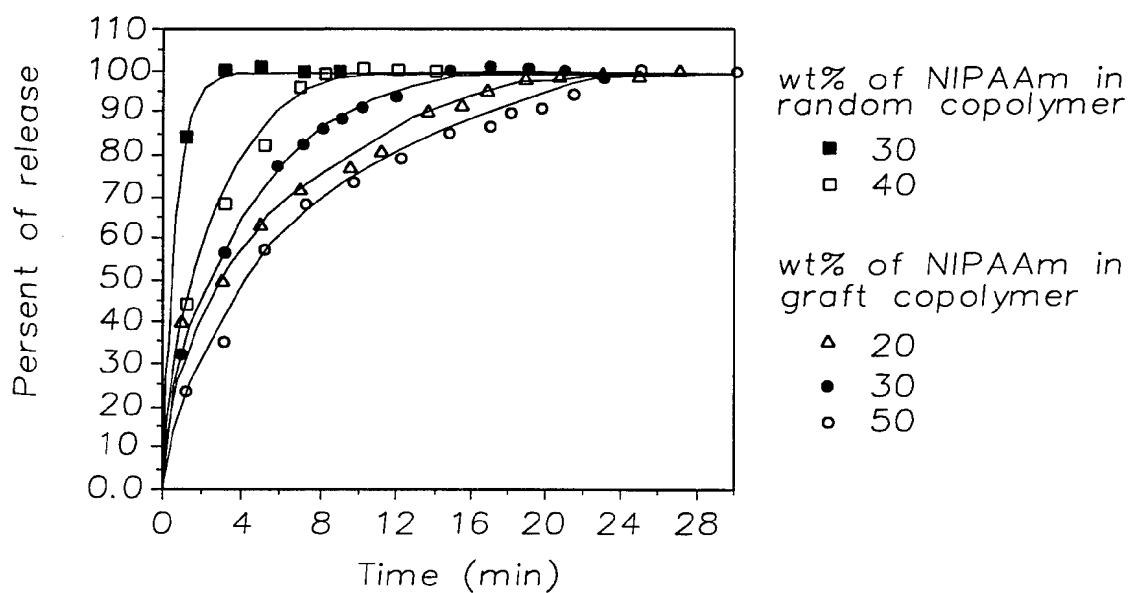
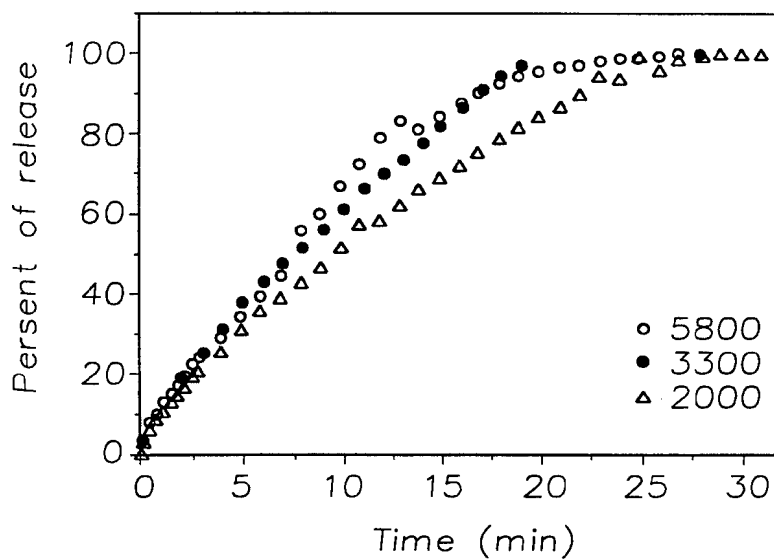
*Fig. 1**Fig. 2*

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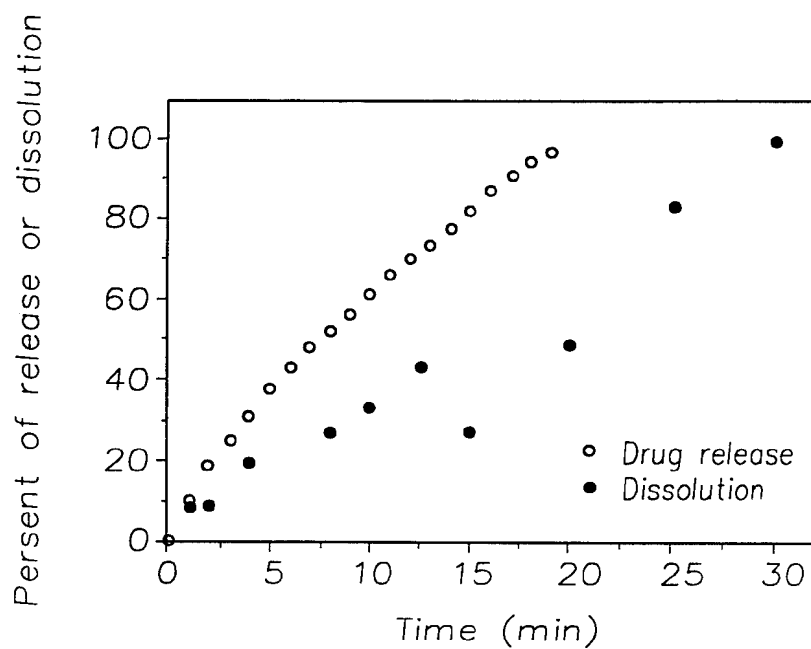
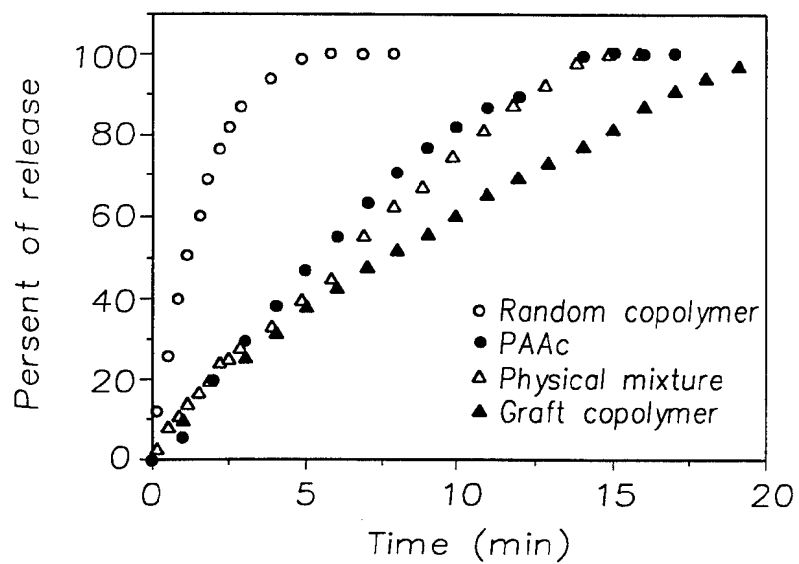
*Fig. 3**Fig. 4*

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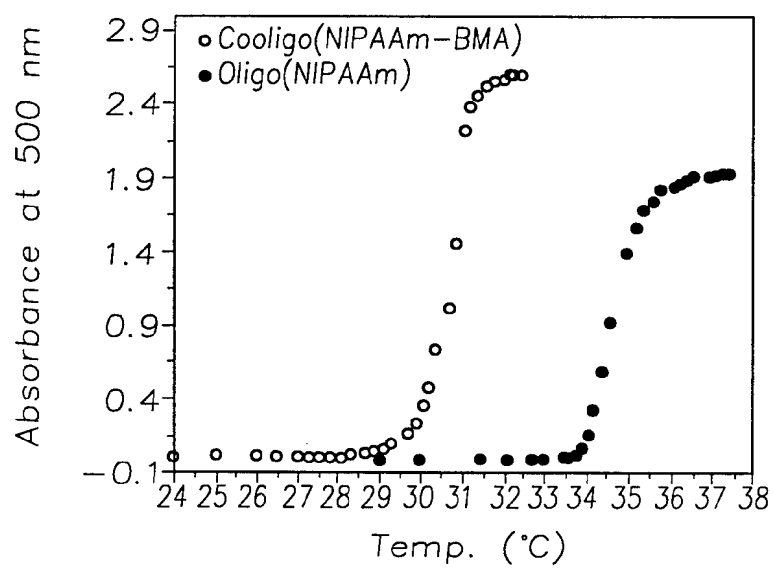
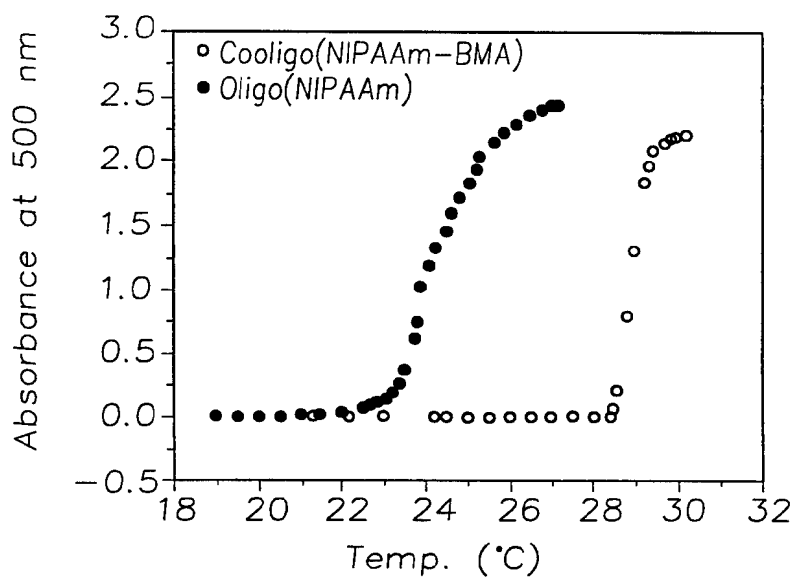
3 / 1 2

*Fig. 5**Fig. 6*

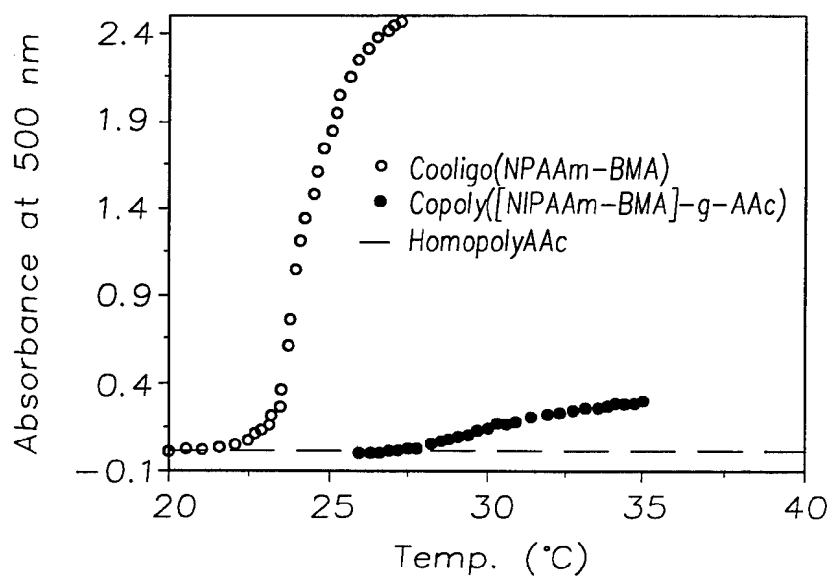
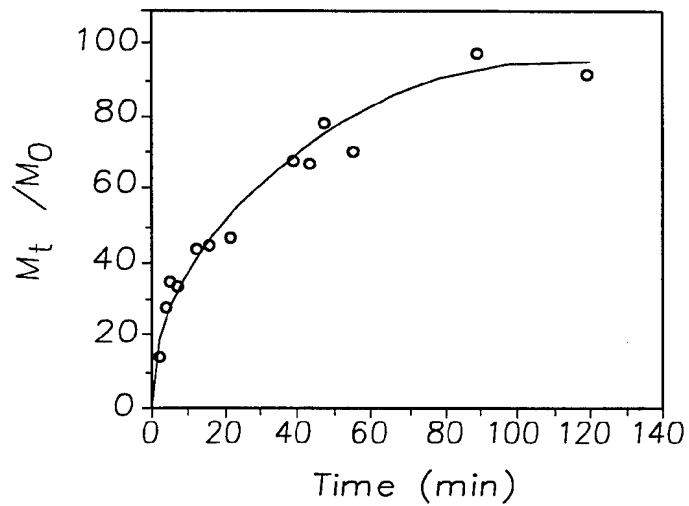


*Fig. 7**Fig. 8*

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*Fig. 9**Fig. 10*

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*Fig. 11**Fig. 12*

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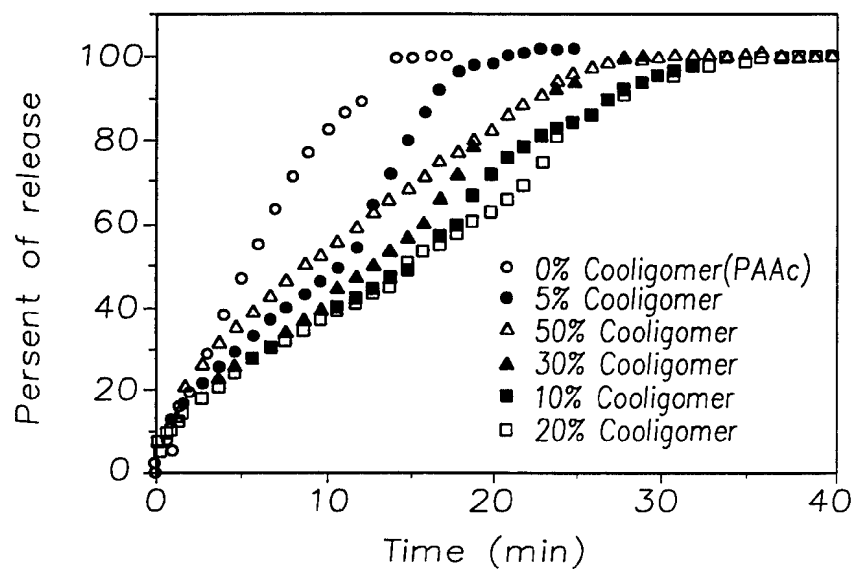


Fig. 13

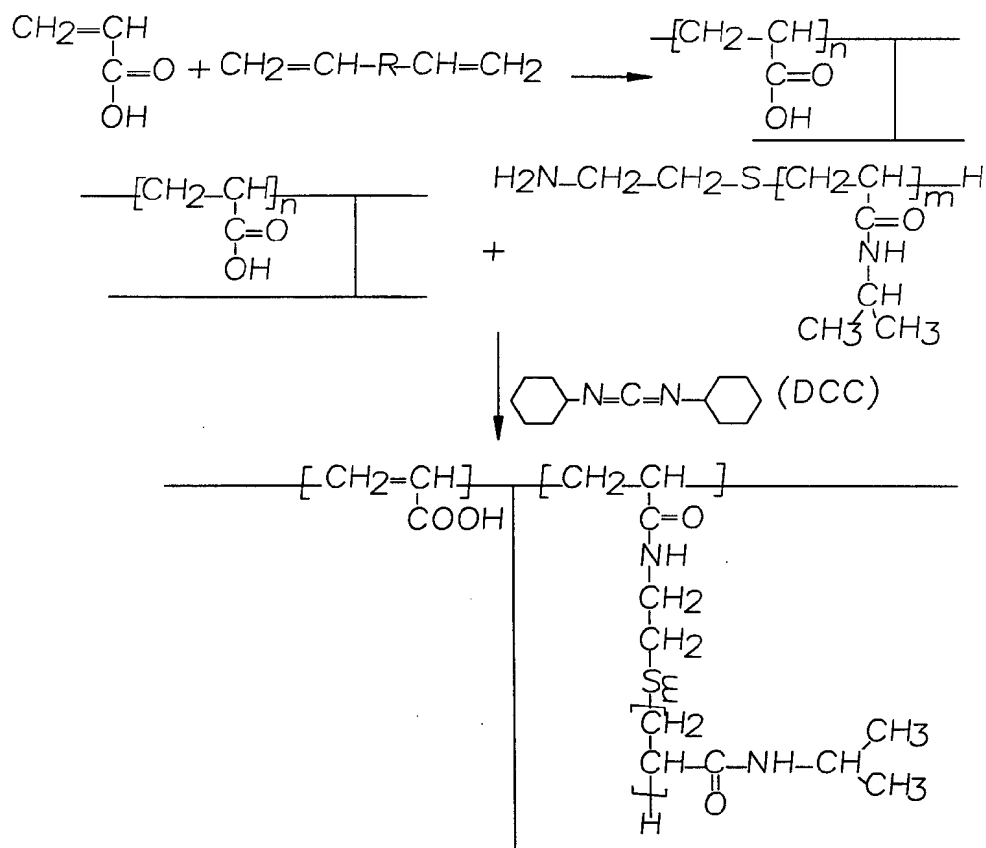
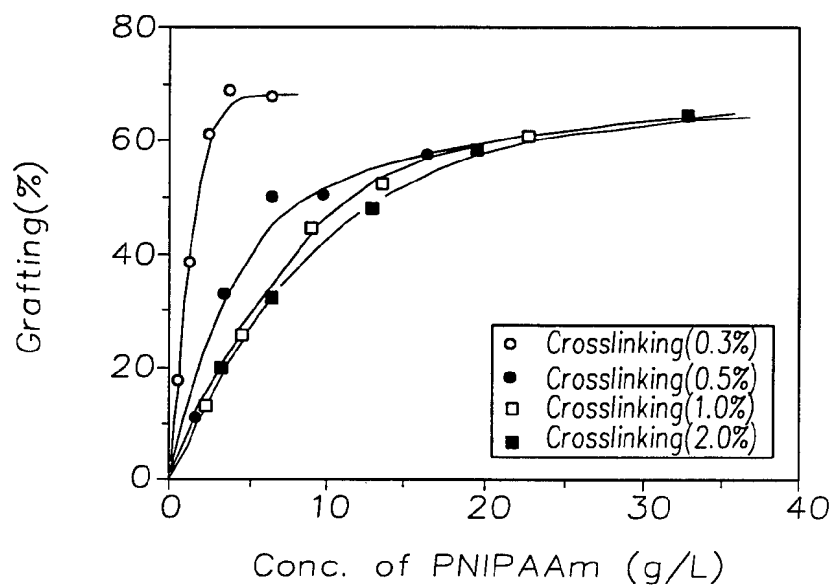
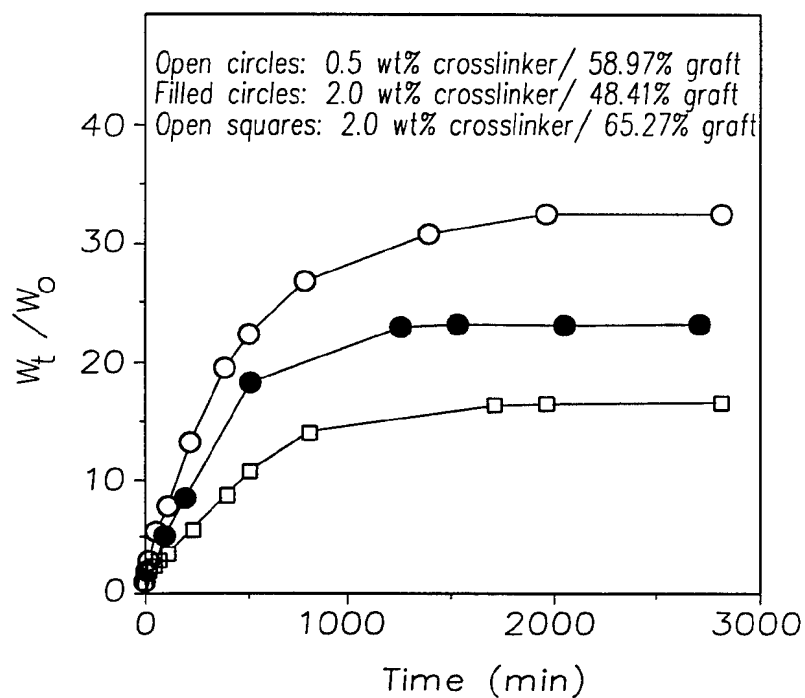
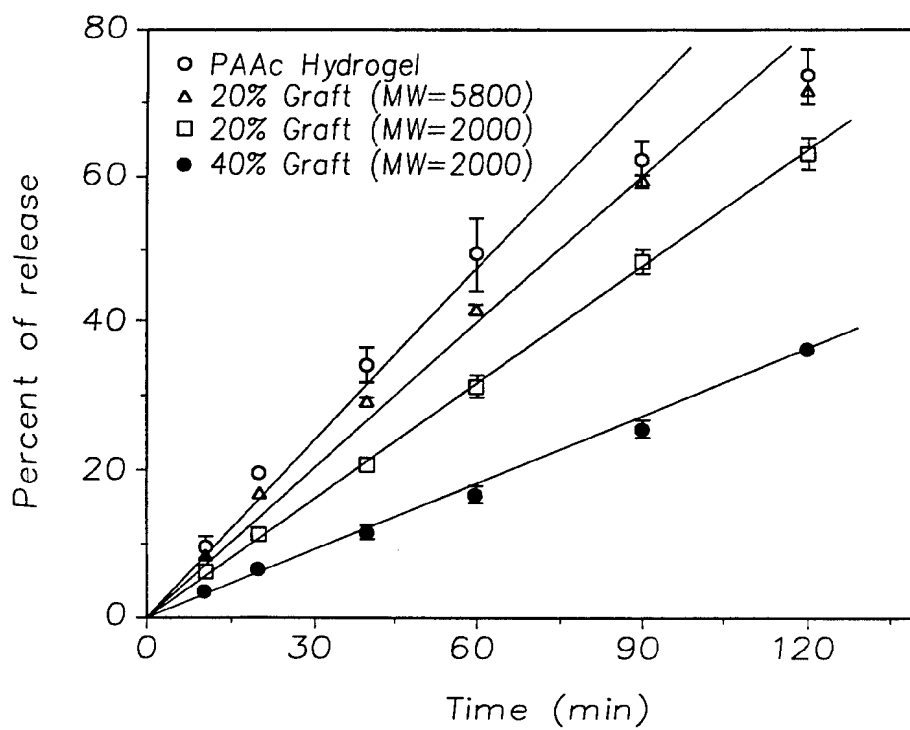
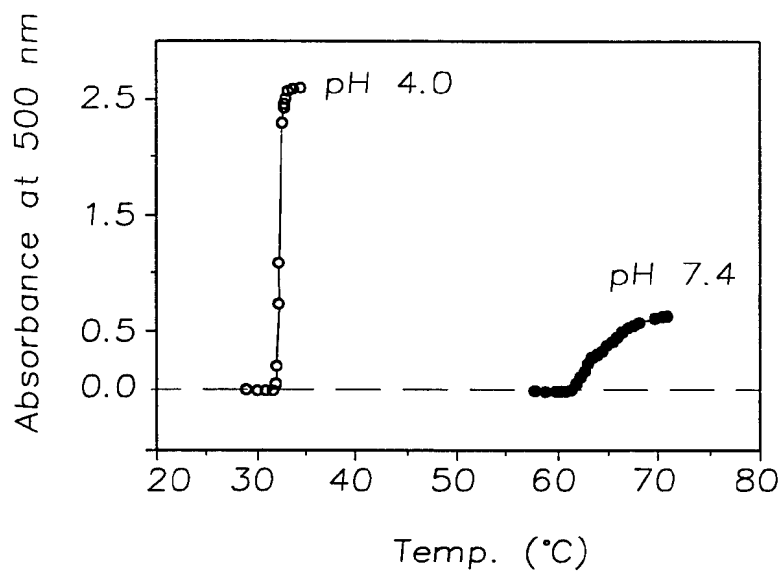
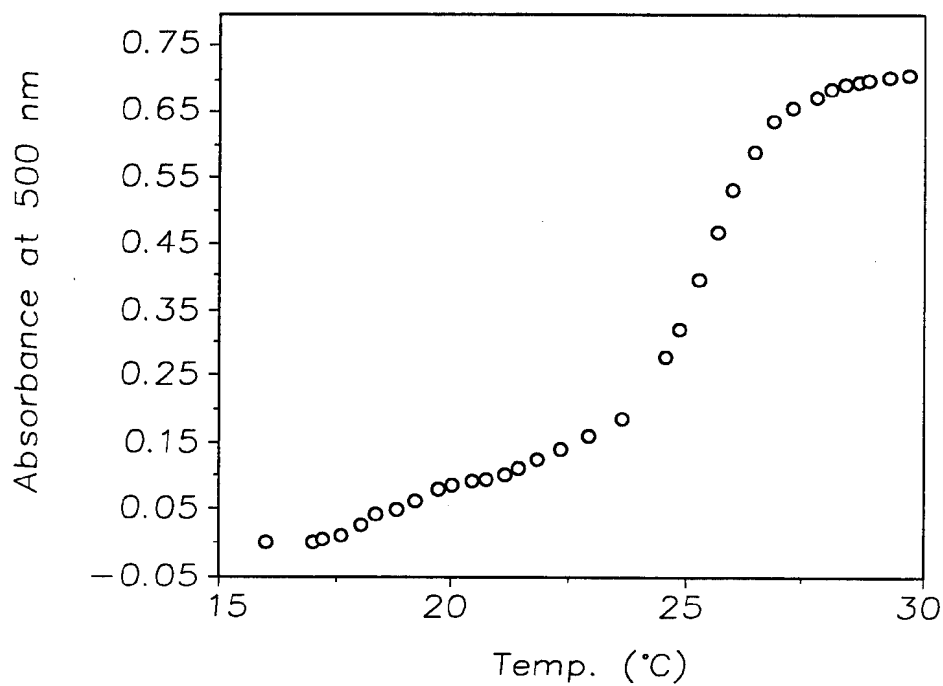
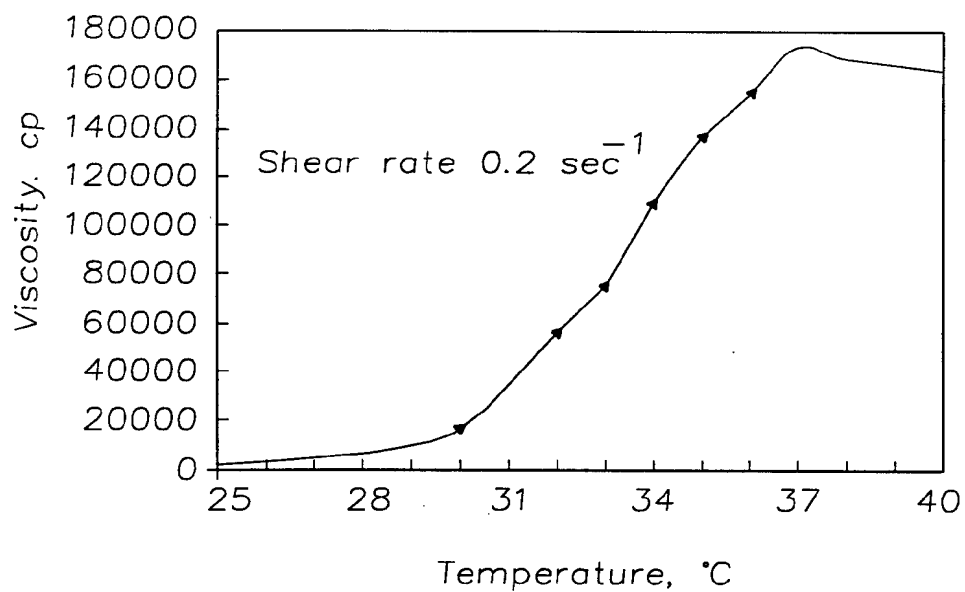


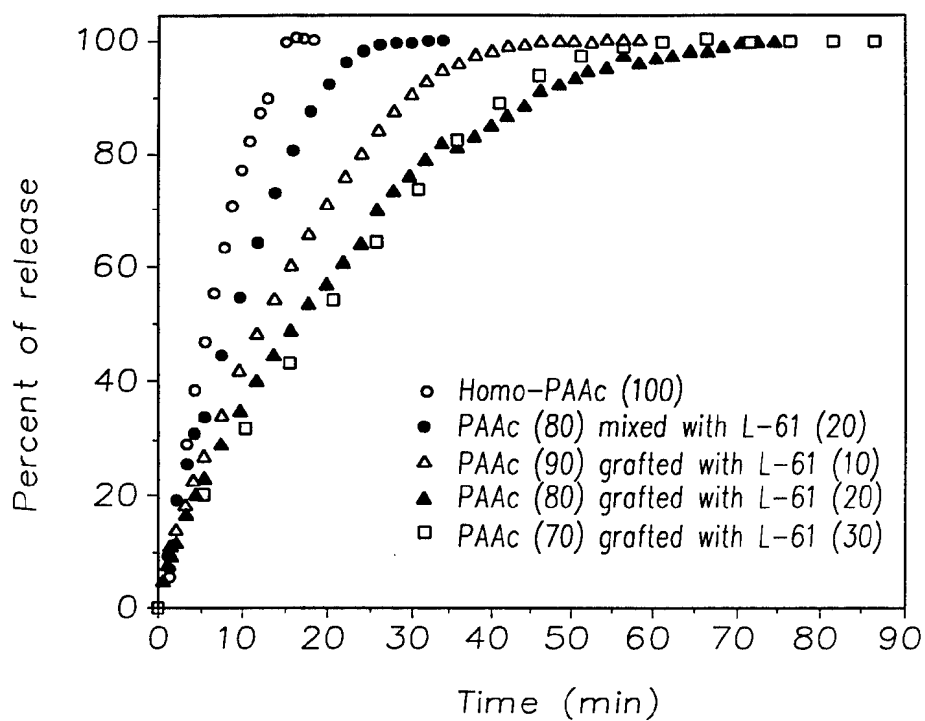
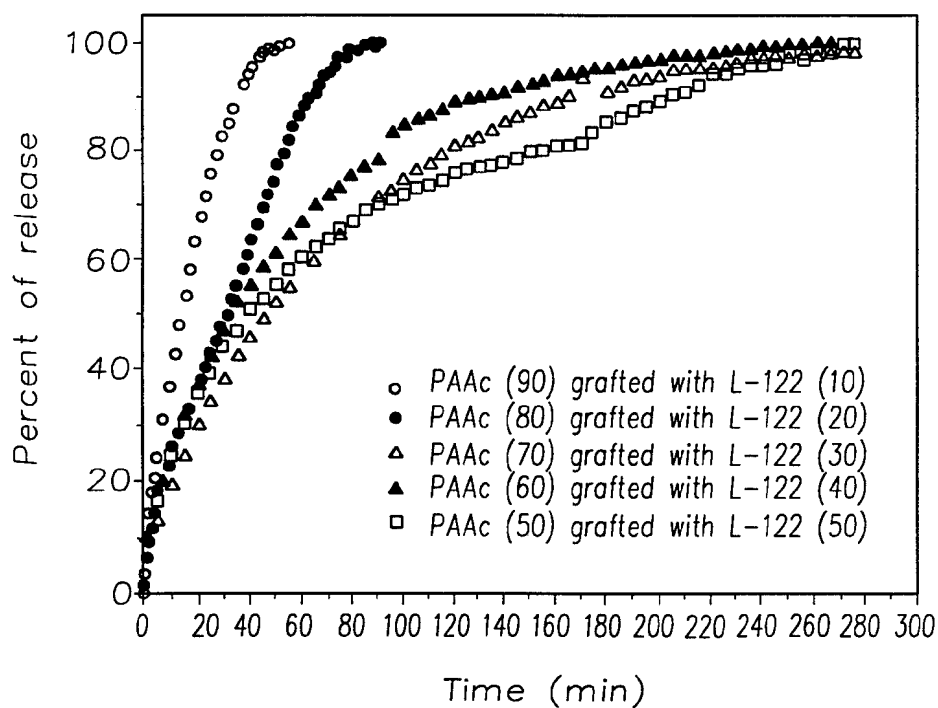
Fig. 14

*Fig. 15**Fig. 16*

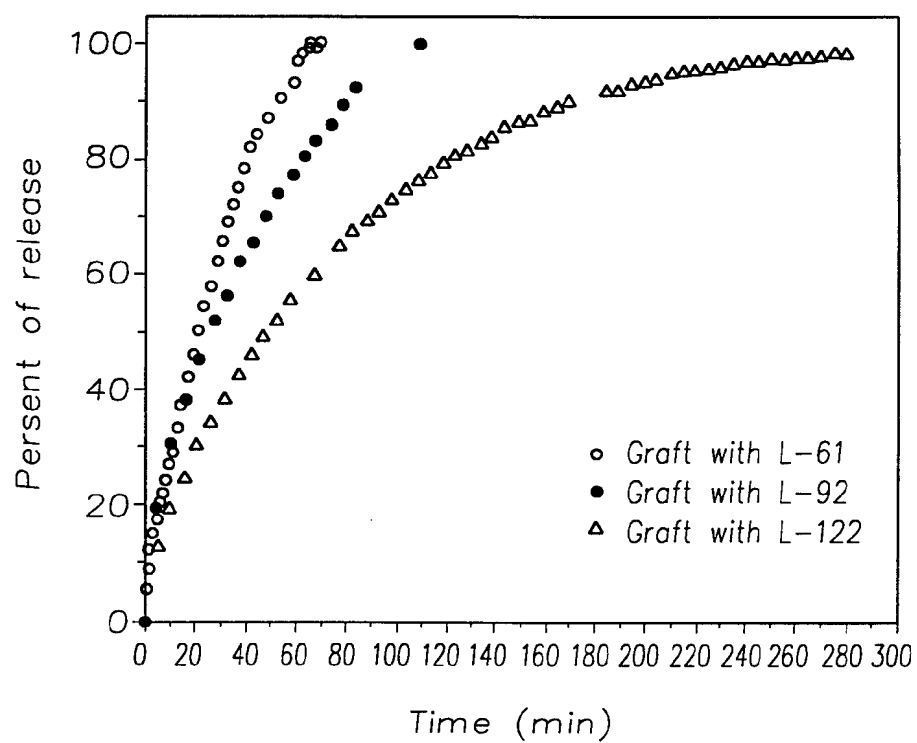
*Fig. 17**Fig. 18*

*Fig. 19**Fig. 20*

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*Fig. 21**Fig. 22*



*Fig. 23*